Global and Geopolitical Environmental Challenges

JÁNOS RAKONCZAI

BUDAPESTI CORVINUS EGYETEM
MAGYAR NEMZETI BANK

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CORVINUS GEO graphia politica oeconomia

Corvinus Geographia, Geopolitica, Geoeconomia

Institute of Geography, Geoeconomy and Sustainable Development
Book Series

Series editors: László Jeney – Márton Péti – Géza Salamin

CORVINUS
UNIVERSITY of BUDAPEST
Geo Institute

János Rakonczai

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Corvinus University of Budapest

Budapest, 2018

Authors of Chapter 12:
János Rakonczai – Viktoria Blanka – Zsuzsanna Ladányi
Authors of Chapter 14:
János Rakonczai – Márton Péti – Géza Salamin

Professional proofreader: Attila Kerényi

Translated by:
Edit Balog (Chapters 1-3, 14-19)
András Petz (Chapter 4)
Viktoria Blanka and Zsuzsanna Ladányi (Chapters 5-13)

English language proofreader: Simon Milton

Figures and Technical Editing:
Viktoria Blanka and Zsuzsanna Ladányi

Photos:
János Rakonczai

ISSN 2560-1784
ISBN 978-963-503-740-7
ISBN 978-963-503-745-2 (e-book)

This book was published according to a cooperation agreement between Corvinus University of Budapest and The Magyar Nemzeti Bank.

Publisher: Corvinus University of Budapest

Cover design and printed: Komáromi Printing and Publishing LTD
Leader in charge: Ferenc János Kovács executive director

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FOREWORD

Foreword from the Publisher

Consideration of environmental issues cannot be avoided in current conversations about geopolitical processes, global challenges, and the long-term future of our World. Therefore, it is highly important to analyse the environmental features of the contemporary global issues that we deal with in our publications.

This book provides an overview of the current state of play of our global environment, citing examples to illustrate common challenges from all around the world. The Author also summarizes the findings of preexisting global models about the future of development and the worldwide policies and activities that have thus far been proposed to handle environmental challenges. This book ends with conclusions about our highly uncertain next few decades. The Author believes that there might still be grounds for a relatively optimistic long-term outlook; however, not without great effort. Therefore, with this book we would like to reach as many readers as possible, including different expert groups, future professionals, and also the general public.

Our school is committed to disseminating geographical knowledge and providing evidence of the importance of geographical information. Professor Rakonczai applies a geographical approach to describing challenges and policies: he synthesizes many different sectoral and thematic issues at the regional and global level, and his evaluations are spatially differentiated. This serves as appropriate proof that the application of a geographical and information-based lens is a must when analysing environmental structures and problems.

Professor Rakonczai has been a mentor of some of the members of our school, and we have learned from him as students and also as professionals. We will be happy if this publication disseminates his knowledge and attitude to a wider audience.

Márton Péti
Director, CUB GEO Institute

INTRODUCTION

The management of globalisation and the related economic, social, political and environmental effects is one of the greatest challenges faced today. Although almost everybody experiences the ever-accelerating process in their own way, individual positions and standpoints generate widely different views about its intrinsic features. The primary aim of this book is to summarize the environmental effects of globalisation and evaluate their social consequences**,** since at first sight, globalisation-related problems are of a socio-economic nature. However, as far as their effects and relations are concerned, they represent environmental problems in almost all cases as well. It is also obvious that global environmental problems can be tackled successfully only by pursuing a socio-economic approach.

In our everyday lives we have rather mixed impressions of the short- and long-term effects of our rapidly changing world. The vast majority of the population live better and longer than their ancestors in previous centuries. On the other hand, the media bombards us with news that appears to threaten our lives and quality of life. If we could eliminate such news about terror attacks, local wars, the migrant crisis, disasters, or the effects of contaminants on sea organisms stemming from the pollution of the oceans, we could lead a pretty good life. Growing lifespans, increasing levels of consumption, and the markedly improving environmental conditions of developed countries make us forget about their environmental impacts. Nonetheless, even living at today's hectic pace we should still pay attention to world-renowned philosophers such as Pope Francis or the recently deceased physicist Stephen Hawking. The Pope's Encyclical,[1] issued in 2015, highlights many of today's environmental issues (Fig. 1), while only a year before his death Hawking warned that within approximately one hundred years we should start colonising a new planet if we intend mankind to survive. If such written signs are insufficient to encourage us to think about our planet's environmental crisis, we may take a look at a photo album[2], which confronts us with evidence about what we have done to our environment.

The past two decades have clearly demonstrated that the process and possibilities of learning advance in parallel. One of the greatest achievements of globalisation, the internet, makes information accessible to nearly everyone. Taking advantage of this situation *we would like to encourage the Reader to think together with us*. To facilitate this, we provide plenty of references with which the Reader may update the book's content, or collect more data about specific topics (although the sources presently available might change or become inaccessible).

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[1] http://w2.vatican.va/content/dam/francesco/pdf/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si_en.pdf

[2] https://populationspeakout.org/the-book/view-book/

Fig.1.Two excerpts from the index of the Encyclical about our environment issued by Pope Francis in 2015

This book attempts to point out essential relationships. In some cases, our work was hampered by a lack, or the opposite – an abundance – of information (for example, changes in data collection methods, or contradictory data even in the case of reliable sources). Also, we needed to weigh up the reliability of 'virtual information'. Material from professional sources was supplemented by personal experience from around the world. We have done our best to provide the Reader with the most creditable information, while we encourage everybody to draw their own lessons and *on the basis of up-to-date information form their own opinions*.

I. FACTS AND THOUGHTS ABOUT GLOBALISATION

1. The process of globalisation

Globalisation is thought to be a phenomenon of the late twentieth century. In fact, while the term is new, the phenomenon isn't. Earlier, its content was so different that we hardly recognized the evidence for it. Moreover, it also moved at a significantly different pace. The roots of globalisation can be traced back to the Age of Discovery, if not earlier, when exchanges of goods and raw materials played a central role, overshadowing the significance of information flows. During the process of globalisation, the emphasis has shifted. Crucial roles have been played by religion, culture, and science, while lately the economy has been a major player. In the last third of the twentieth century, the environment was forced to take a backseat alongside this, then information technology exploded, and now it seems that politics are also about to gain the upper hand. Events and processes that we have little influence over, such as increases in energy prices, environmental pollution without boundaries, or decisions made hundreds of miles away about the establishment or shutting down of a factory are gaining momentum.

A vital new element of the change is that the representatives of the still dominant economy have had to realize that *the relationship between the global economy and global ecology has changed direction*. While some decades ago, after becoming cognisant of environmental problems, we worried about the environmental consequences of economic development, we now need to find solutions for the socio-economic effects of ecological stress. Similarly, while in the past the commercial dependence of countries used to be a decisive factor, present-day environmental interdependency can contribute to problems through global warming or regional pollution, for example.

How else has globalisation changed – that makes us think of it as a new phenomenon? This process is called the *explosion of globalisation,* and it started in the late 1980s. The Eastern European political transition, the disintegration of the Soviet Union, and the end of bipolar world politics opened the door to fundamental political and economic changes. Technological liberalisation began (with the abolition of the so-called CoCom list the markets for modern technology opened up), and the movement of capital accelerated. Simultaneously, an informal revolution took place (in computerisation and telecommunications) generated by developed countries. Basically, this was the era in which the conditions for an accelerating globalisation were laid down. The world witnessed fundamental changes in technical development (transportation was supplemented by flows of information), economic policy (the free movement of capital and material assets has accelerated) and political conditions and intentions.

In attempting to outline what globalisation means to our contemporaries, we can say that it has a significant impact on almost every area of our lives, and it has changed the opportunities of not only individuals but also whole sectors by many orders of magnitude. Without taking all the factors into consideration, it is worth attempting to estimate the rate of change of some typical elements of globalisation.

Progress in *transportation* has increased by about three orders of magnitude, meaning that while in the past we travelled and transported at a few kilometres per hour, travelling at anything less than one thousand kilometres per hour is now not extraordinary. This allows us to take short holidays in distant places. Similarly, we are able to obtain fruit and other perishable goods from all over the world – this involves only a question of making a market assessment. On the other hand, it takes just moments for infectious diseases to spread around the planet. Voyages used to take longer than the incubation period of most diseases, and epidemics could be stopped by imposing quarantine at ports. In our fast-paced world it is now difficult even to detect the source of many diseases of this kind. No wonder the film industry has exploited this topic. 'Innocent' transport can also cause substantial ecological change. On Guam, for example, a certain species of snake that was accidentally brought onto the island is now held responsible for the extinction of bird and mammal species.

The globalisation of *healthcare* may best be measured in terms of accelerated population growth, with an efficiency estimated as 1-2 orders of magnitude. This means that in earlier periods of history it took hundreds or even thousands of years for the population to double. In the middle of the twentieth century, however, this process took only 35-40 years. (For more details, see Chapter 4.1)

This multi-layered progression of science and technology has brought about consequences that can hardly be described. The transformation of the environment has accelerated. Instead of spades and shovels, enormous excavators reshape the landscape. Instead of fly swatters, 'efficient' chemicals with often incalculable effects 'protect' us from the damage that insects cause. However, these substances also played a major role in bringing about the so-called Green Revolution. The warlike achievements of science have resulted in a 10^{6-7} rise in the efficiency of weapons. High-precision measurement has supported the theory and practice of science in various fields (e.g. satellite navigation, astronomy, and material testing). The perspectives created by information technology, medical science and biotechnology are barely comprehensible to mankind.

The first step in *economic* globalisation involved the simple exchange of goods. For decades this was fuelled by the predominant, efficiency-based process of exporting and importing. Companies' profit-oriented attitudes won out over demand for national self-sufficiency. The former produce where it is cheaper, often ignoring social and environmental consequences. Multinational companies often internally shape important segments of the trade in global merchandise, and their decisions frequently directly influence other countries' economies. Processes that take place in another hemisphere may often have massive impacts on actors totally independent of them. For instance, it can pay to intensely watch developments in interest rates in the United States, as these can determine fundamental economic processes. We find it self-evident that we can set off and discover the world with dollars or euros (the world currencies) in our pockets. There is hardly a place in the world where we can't enjoy Coca Cola or a hamburger, products which are the simple consequences of economic globalisation. The list goes on.

Both the speed of transmission and the globalisation of *information* have undergone a revolutionary change. How far we have come from the pace of the Inca couriers, or native American smoke signals! We take for granted the watching of any live broadcast, whether a football match, the main events of the Romanian revolution, the bombing of Baghdad during the invasion of Kuwait, or 9/11. Financial specialists wake up with data about the Far Eastern stock market and go to bed with data about New York's. It is not unusual for the participants of virtual teleconferences to meet only through a screen. About 25 years ago, cell phones were available only to the 'privileged'. With slight exaggeration, we can say that many of the present young generation now change their phones more frequently than their shoes, and even two- or three-year-old children use them more confidently than their grandparents.

The globalisation of *information collection* has changed dramatically as well. Developing safe ways of remote sensing played an essential role in ending the Cold War (it wasn't necessary to physically spy on the spot, and the vital instruments of war couldn't be hidden from satellites either). We can find increasing amounts of useful public information on the internet, which allows us to learn about almost anything from our armchairs. Previously, it was mainly the omniscient professor, who brought books from the West and carefully locked up after showing it to the colleagues, thus, could hinder the spreading of modern science for even a decade. Today, the internet allows us to collect information about the most recent scientific achievements and bring students more up to date about topics than their teachers. The author of this book made good use of such knowledge as he was able to continuously update his material and check potentially contradictory data. Such information, however, may be misleading, since with such an abundance of sources we may come across material of dubious scientific background. Web cameras that promote public security may increase security, and even help identify cases of criminality. Also, we are able to monitor our homes from thousands of kilometres away. At the same time, the web poses numerous threats to its users, such as various types of cybercrime, leaks of personal information, the enhancement of swift communication between terrorists, or even external intervention in elections (as alleged with the recent American election). A couple of decades ago, geographical maps at a scale of 1:200 were classified as top secret (e.g. in Hungary – although we didn't understand why). Now, with Google Earth we can not only count the swimming pools in the neighbourhood, but archaeological objects in distant countries have also been discovered using this tool. Unfortunately, the program is also a 'perfect' device for planning explosions.

Data about cell phone and internet use reveal (Fig. 1.1) that the advantages of globalisation are increasingly being used by mankind. Cell phones and the internet, whose success story started in the early 1990s, are now part of our everyday lives. While the internet was initially mainly used in developed countries, after 2000 there was a real revolution in its use in less developed regions. It is a notable fact that between 2000 and 2016 the number of internet users increased sixfold in Europe, but in the meantime in the Middle East it increased by fifty times, and in Africa almost by a hundred (Table 1.1). Consequently, the internet has become an integral part of our lives across the world (Fig. 1.2).

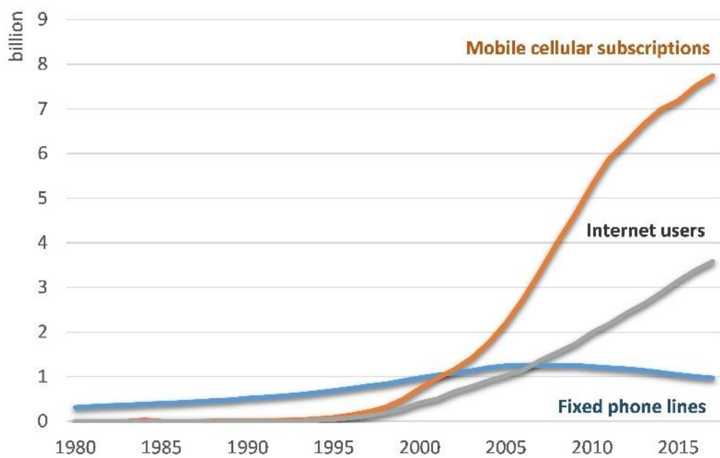

Fig.1.1. Number of mobile cellular subscriptions, internet users and fixed phone lines (1990–2017) (Source: IWS, Worldbank[3])

[3] https://www.internetworldstats.com/stats.htm , https://data.worldbank.org/indicator/IT.MLT.MAIN?view=chart

Table 1.1. Internet users per region at the end of 2017
(Source: based on data from IWS[4])

Continent/ region	Popu-lation (million)	Proportion of global population (%)	Number of internet users (million)	Proportion of internet users in the region (%)	Increase in number of users (%) 2000-2018	Proportion of global internet users (%)
Africa	1288	16.9	453	35.2	9941	10.9
Asia	4207	55.1	2024	48.1	1670	48.7
Europe	828	10.8	705	85.2	570	17.0
Latin-America/ the Caribbean	652	8.5	437	67.0	2318	10.5
Middle East	254	3.3	164	64.5	4893	3.9
North America	364	4.8	346	95.0	219	8.3
Oceania/ Australia	41	0.6	28	68.9	273	0.7
World	7634	100	4157	54.4	1052	100

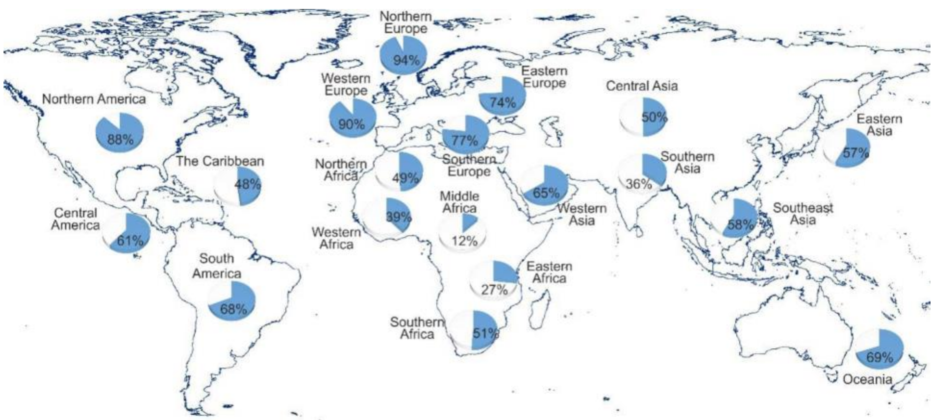

Fig. 1.2. Percentage of internet users in different regions of the world in January 2018 (Source: data from IWS)

At the beginning of 2018 more than four billion people enjoyed its benefits. At a regional level there are only two African regions where less than one third of the population access it (although life expectancy is outstandingly low in these areas). Cell phones have become seemingly indispensable in a similarly

[4] https://www.internetworldstats.com/stats.htm

short time. At the beginning of 2018, the eight-and-a-half billion appliances in circulation were being used by 5.1 billion people, with many having two or three phones. Although there was a surge in the number of landline phones at the beginning of the 1990s, with the appearance of cell phones their popularity quickly decreased, with a significant drop since 2006 (1.26 billion compared to fewer than 1 billion in 2017). Owing to the rapid spread of smartphones, the lovechild of the internet and the cell phone, since 2016 – only seven years after their debut on the market – internet use using a smartphone is more common than through a desktop computer (Fig. 1.3). This is how cell phones have become the most widespread technological wonder in less than a quarter of a century. With the speedy spread of the internet, the role of television in providing information to people has gradually declined. There are now about 1.6 billion appliances in use by some 3-4 billion people.

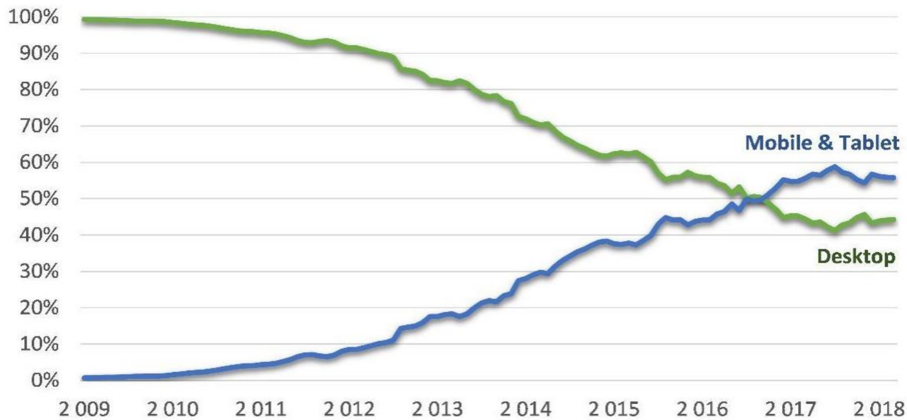

Fig. 1.3. Landline and mobile internet access compared (October 2009 – March 2018) (Source: data from StatCounter,[5] supplemented)

The globalisation of *environmental problems* had become clear by the last third of the twentieth century. With the escalation of industrial activity, water and air pollution increased. The phenomenon of acid rain and the potential for the greenhouse effect were mentioned as early as in nineteenth-century scientific articles. Still, recognizing the hazards of these took more than a hundred years. The first program for measuring carbon dioxide, the main element responsible for the greenhouse effect, was only launched in the late 1950s. It was mainly in the USA that attempts were made to discredit research findings about global warming through the deliberate

[5] http://gs.statcounter.com/press/mobile-and-tablet-internet-usage-exceeds-desktop-for-first-time-worldwide

spread of misinformation. At first, forest damage caused by acid rain was thought to have natural origins, and only became the centre of analysis as an environmental issue at the end of the 1970s. Recognition of the atmospheric phenomenon known as the 'ozone hole' occurred in 1985. (We discuss the above-described problems in later chapters.)

The second half of the twentieth century was a significant period in the globalisation of *politics,* too. After the end of the Cold War, the UN also took significant political role. Associated with the UN the *globalisation of environmental politics* began in 1972 with environmental conventions and conferences in Stockholm, Rio and Johannesburg.

In the past decades, in the form of a silent guest, a common language, an important element of *social globalisation,* joined the club. It is becoming obvious that *English is the language of international communication*. Not long ago, at high-level international scientific conferences multilingual simultaneous interpretation was provided, which is nowadays only typical at political events. This tendency is supported by the fact that in Japan the introduction of English as an official language has been contemplated. Another example comes from the present author's personal experience. About 20 years ago I heard a Chinese organiser of a conference in Singapore complaining how difficult it was to enrol his son at a university where courses were taught in English. Of course, social globalisation has both centuries-old and new elements as well, like global migration flows (e.g. the colonization of America by Europeans) or the mixed marriages that are virtually commonplace these days. Also, due to our globalized social relations, it is not unusual that foreign players predominate in the teams that play in major football championships.

The dynamic development of *international tourism* can be regarded as part of the phenomenon of social globalisation, and has grown by more than 60 times in about 50 years. Although it can be slowed by a major international event such as the Iraq War, 9/11 or an economic crisis, this soaring tendency appears to be unstoppable (Fig. 1.4). International tourism has become a real industry. In 2016, on average, every sixth person took part in it (1.235 billion people). Revenues between 1990 and 2014 almost increased sixfold (in 1990 they reached $264 billion, while in 2014 tourism was worth $1522 billion), equal to half of the revenue from fuel, and slightly exceeding revenue from food exports (worth $1486 billion in 2014). The main tourist destination is Europe, which 'owns' half of all international tourism (Fig. 1.5). In 2016, the most popular tourist destinations were France, the USA, Spain, China and Italy, but it was the Chinese who spent most on international trips ($261 billion), almost equalling the total spending of the USA, Germany and Great Britain ($268 billion).

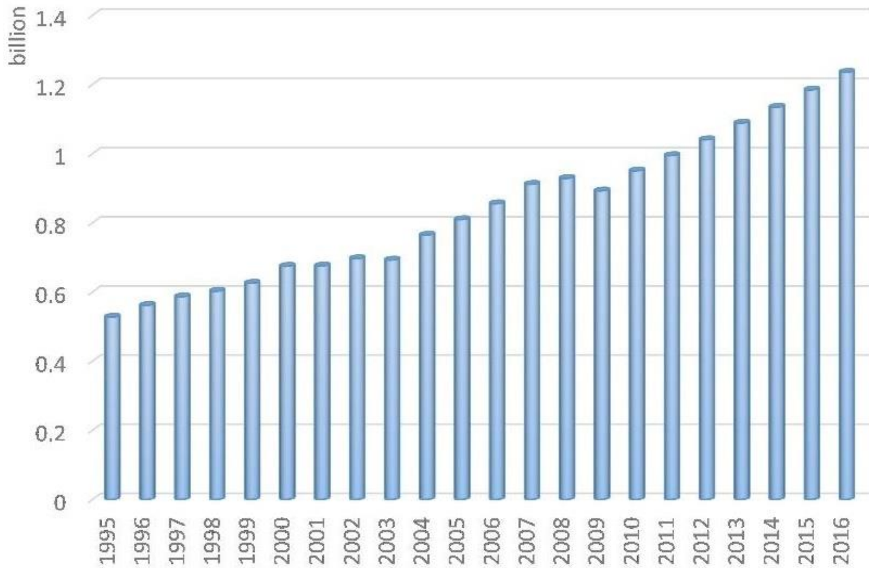

Fig. 1.4. Number of international tourists (1995–2016)
(Source: based on data from UNWTO)

Fig.1.5. International tourism destinations in 2016 (million people/%)
(Source: based on data from UNWTO 2017)

2. Globalised world economy

Since World War II, the world economy has been profoundly transformed. A significant increase in production has been combined with dynamic development in trade, and once strictly closed national economies have become open and market sensitive. This change is clearly demonstrated by the fact that while global production increased 12 times between 1950 and 2007, international trade grew thirtyfold. This increase has accelerated sharply since the mid-1970s. International markets expanded dynamically until the economic crisis of 2008, when more than 30% of all production was exported (Fig. 2.1). The effects of the crisis caused a slight drop in the international trade in goods. Now it seems that, owing to changes in the structure of goods, a period of stagnation has begun, starting in around 2006.

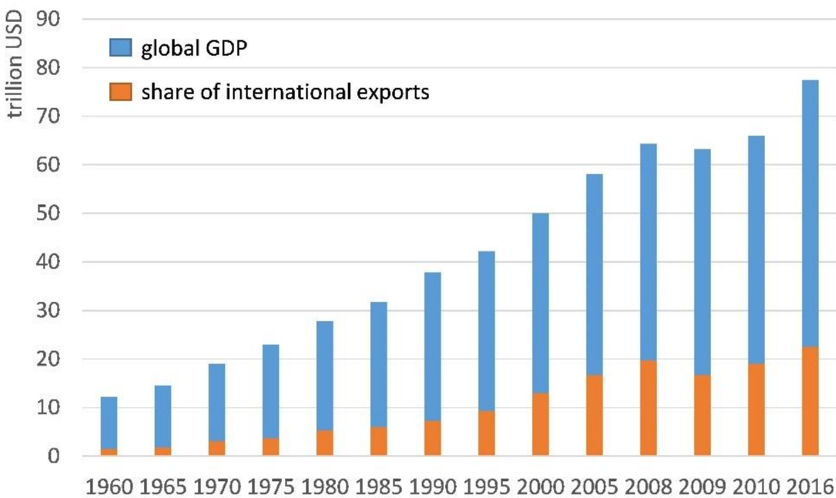

Fig. 2.1. Global GDP and the share of international trade in goods in GDP[6] (1960–2016) (Source: Worldbank data)

There has been *extensive change in the structure of trade,* especially considering the proportions of agricultural and industrial goods. During the past 50 years or more, as a result of the increase in industrial products, trade in agricultural products has been relegated to the background (Fig. 2.2). In 1950, agricultural exports accounted for nearly 47% of total turnover. By 2005, this figure had fallen to below 10%, while the proportion of industrial products had

[6] GDP calculated in 2010 prices.

risen from 38% to 72%, meaning that the declining share of agriculture (already shrunk to one-fifth of the size of earlier) was juxtaposed against a nearly doubling industry. We should not be surprised at this if we take the material situation into account. Even if there were an abundance of food, food consumption wouldn't increase in a manifold way, not even in the most famine-stricken areas. Conversely, the market for consumer goods has reached almost biblical proportions in the past fifty years. Mechanization means that products previously barely known (the television, washing machine, refrigerator, telephone, etc.) have become part of our everyday lives, and a wide range of brand-new products (computers, hi-fis, videos cameras, cell phones, etc.) have appeared and spread across the world.

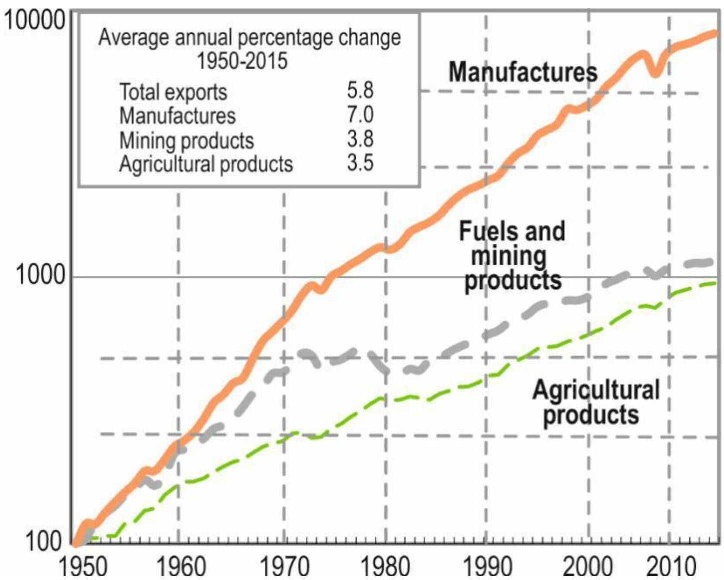

Fig. 2.2. World merchandise trade volume by major product group (1950–2015) (Volume indices, 1950=100) (Source: WTO 2016[7])

Since 2006, a minor change has been taking place in the trade in world merchandise. The growth rate of the market share for agriculture, which was 5% on average between 2006 and 2016, has overtaken that of the processing industry (although the latter still plays a dominant role), while the share for raw materials has suffered a severe setback since 2013. As a result, in 2016 the share of agricultural trade was 60% larger and industrial trade 37%, but trade in raw materials was 10% less than in 2006 (Fig. 2.3). As many suspect, this dramatic turn might be due to reasons beyond petroleum production and related prices,

[7] https://www.wto.org/english/res_e/statis_e/world_commodity_profiles16_e.pdf

which are sometimes difficult to understand (we discuss these later), and the broad distribution of renewable energy resources.

World merchandise trade, both in exports and imports, is dominated by five economic superpowers (the EU, China with Hong Kong, the USA, Japan, and South Korea) that account for more than two-thirds of total trade. (It is important to point out that roughly two-thirds of EU trade takes place within the Union.)

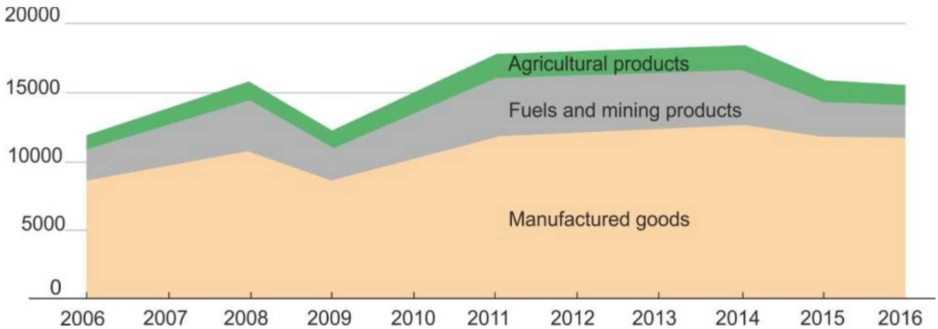

Fig. 2.3. World merchandise trade by major product groups (2006–2016) (billion USD) (Source: WTO 2017)

An illustration[8] designed in 2017 that displays leading national exports communicates a great deal of interesting information. It shows that exports are dominated by fuel according to the size of territory (North America, North Africa, the Middle East, Russia, and the former Soviet countries in Asia). Western and Central Europe, Japan and Mexico mainly export cars, Southeast Asia is the leading exporter of computer products, and Australia and the southern and western regions of Africa primarily export ores.

Apart from the exchange of goods, working capital investments have increased significantly, and the average daily turnover of stock markets has multiplied, entailing dynamic growth in international financial flows.

These data indicate that the interdependency of countries has never been so developed throughout history. The main losers of the drastic restructuring of the trade in world merchandise described above have been underdeveloped, non-industrialized countries with continually decreasing exports and rising imports. This process has led a number of countries into a dead-end debt trap. Conversely, countries with substantial petroleum reserves which had previously

[8] At the time of writing this book, available at https://d36tnp772eyphs.cloudfront.net/blogs/1/2017/09/export_map.png . By zooming in on the map you can obtain more information: e.g., the main export product of Nepal is flavoured water, Brazil, which used to be the biggest coffee exporter, is now engaged in exporting soy, and Moldova exports insulated wire.

been lagging behind have emerged as the outright winners of the accelerating global economy and have been able to achieve unthinkable prosperity, although there are some exceptions.

The economic strengthening of countries and multinational companies was needed for the acceleration of trade in world merchandise. Since the second half of the twentieth century there has been far-reaching change in the economic performance of countries. The most spectacular change involves Japan, China, India, South Korea, Brazil, Mexico, Spain and Italy, while the latter two were less developed in the 1950s. These countries, and the great petroleum exporting ones, have contributed to the fact that formerly developing countries are today literally developing. Their share of trade in world merchandise is continuously increasing, to which inflowing external capital also contributes.

Table 2.1. GDP of the world's 15 economically strongest countries (1960–2018) (Source: based on data from Worldbank and IMF)

Rank order 2016	Country	GDP (billion USD 2016)				GDP ratio			GDP/ppp	
		1960	1990	2000	2016	2016/ 1990	1990/ 1960	2016/ 1960	2016	2018*
1	USA	543	5980	10285	18624	3.1	11	34.3	18624	20200
2	China (with Hong Kong)	61	361	1376	11520	31.9	5.9	188.8	21451	25478
3	Japan	44	3140	4888	4940	1.6	71.4	112.3	5267	5546
4	Germany		1765	1950	3478	2			4041	4308
5	UK	72	1093	1635	2648	2.4	15.2	36.8	2828	2980
6	France	63	1275	1368	2465	1.9	20.2	39.1	2774	2932
7	India	37	317	462	2264	7.1	8.6	61.2	8718	10340
8	Italy	40	1177	1142	1859	1.5	29.4	46.5	2324	2378
9	Brazil	15	462	655	1796	3.9	30.8	119.8	3147	3330
10	Canada	41	594	742	1530	2.6	14.5	37.3	1598	1336
11	South Korea	4	279	562	1411	5.1	69.8	352.7	1832	2127
12	Russia		517	260	1283	2.5			3397	4143
13	Spain	12	535	626	1237	2.3	44.6	103.1	1694	1848
14	Australia	19	311	415	1205	3.9	16.4	63.4	1129	1296
15	Mexico	13	263	684	1047	4	20.2	80.5	2280	2498
World	total	1366	22595	33568	75848	3.6	16.5	55.5	120603	167782

* Estimated data (IMF)

Based on their economic performance in 2016, there are 15 countries whose yearly GDP exceeds $1000 billion (Table 2.1). However, in the past fifty years these countries have taken distinctly different development paths before reaching their current positions. Many countries, but mainly Japan, South Korea, and Spain, significantly progressed between 1960 and 1990. China and India, on the other hand, have been continuously rising since 1990. China's development is particularly fast. In 1960 its economic performance amounted to only one-ninth of the USA's, while in 2016 the figure was 62%. According to some predictions, in the first half of 2020 China may well have the strongest economy in the world. As far as purchasing power parity (PPP) is concerned, it has already overtaken the USA. The path of GDP growth highlights many interesting things (Fig. 2.4). Remarkably, the Japanese economy, traditionally considered to be strong, has been stagnating since 1995. With the exception of a short hiccup following the crisis of 2008, the economy in the USA has been expanding steadily and dynamically. The Chinese economy has been improving rapidly since 2005, although in the past one or two years it has slightly slowed down. Also, the Indian economy was kick-started in 2005, but the rate of growth was only a little more than that of the leading economies in Europe.

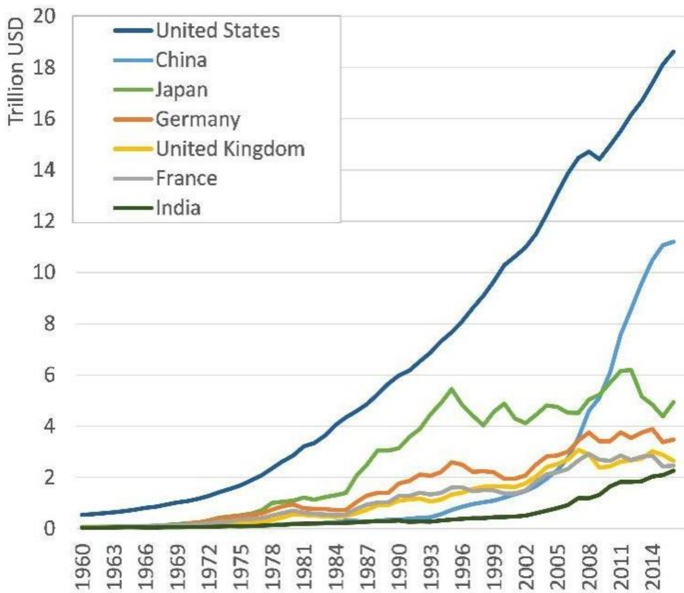

Fig. 2.4. Evolution of growth of the world's seven economically strongest countries (1980–2016) (USD 2010) (Source: Worldbank[9])

[9] Find data for more countries at https://data.worldbank.org/indicator/NY.GDP.MKTP.KD

The price of petroleum greatly affects the economic efficiency of petroleum-market-dependent countries which are rushing up behind the seven most powerful economies (Fig. 2.5). These countries experienced rapid development between 2000 and 2008, and following a slowdown in 2009 took off again until 2013. Russia suffered the greatest economic decline resulting from the decrease in petroleum demand which led to a significant decrease in price. Special mention should be made of Saudi Arabia, which can be found in twentieth place on the size-of-GDP list of 2016. Its economic performance decreased and stagnated following the first oil price shock of the late 1970s until the year 2000, then due to another price increase it grew considerably. In spite of the fact that it has a more single-product-type economy than Russia, insecurity about oil prices affected the latter much more deeply.

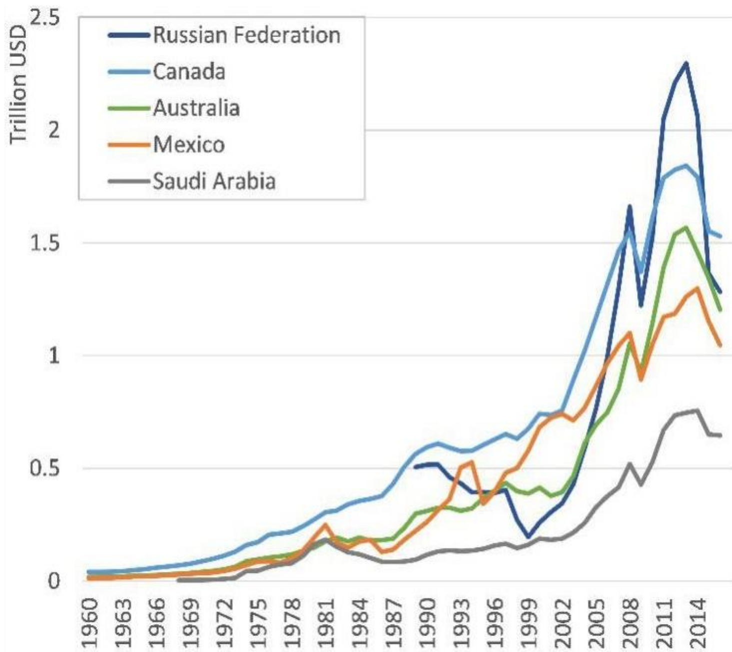

Fig. 2.5. Evolution of growth of some economically strong but petroleum-dependent countries (1980–2016) (USD 2010) (Source: Worldbank)

In the process of globalisation it is *multinational companies* that come under most attack. They receive criticism for taking an indifferent attitude towards citizens, while having tremendous economic power. Their activities are driven by pure economic interest, not by social sensitivity. The average citizen can hardly imagine the economic power of these supernational companies. At the end of the 1990s the total annual sales of the 200 biggest companies exceeded the total GDP of all the world's countries, excluding the top ten countries. These 200 biggest companies account for more than one-quarter (27.5%) of global economic activity, while they employ only about 1% of the world's workforce. These cumulated data mask a couple of interesting facts, however. From the formerly mentioned 200 companies, 82 were American, a fact which might be fuelling anti-American attitudes in many parts of the world. Forty-one were Japanese, 20 were German, and 17 were French, meaning that four countries own four-fifths of the biggest companies.

After the millennium the role of multinational companies increased. Indeed, the brake on economic development in the second half of the 1990s resulted in the public sector's gradual withdrawal from international economic processes. Meanwhile, the private sector, which is technically equivalent to multinational companies, spread dynamically.

As regards the distribution of power at an international level[10] there has been a major transformation in the past twenty years. Although USA-centered corporations still prevailed in the group of the 200 biggest companies in 2016, their number has now declined to 63. Conversely, in China the rapid development of economy brought about the strengthening of large companies. There are 41 of them in the top 200, but the strongest ones have worked their way up to 2nd-4th place. The stagnation of the Japanese economy is well reflected in the decline in the position of their large companies, while their number in the ranked list of 200 has halved to 20. Germany and France have also lost some of their economic importance (14 companies each on the list)[11]. Nevertheless, these five countries account for more than three-quarters of the 200 strongest companies, with these 200 companies responsible for 23.2% of world GDP.

According to a survey[12] conducted in 2017 that examined the 500 biggest companies, the former are responsible for 36% ($27.7 trillion) of world GDP while employing only 67 million people.

Comparison with national economic performance demonstrates the size of the corporate giants. On a common list that includes country GDP and the revenue of large companies, the biggest company (Walmart) occupies only 25th place, while there are five companies among the first 50 places. However, in the

[10] These are mainly multinational companies, but there are some national ones, too.

[11] There are two reasons why we decided not to go into more detail on a country level. Many large companies are involved only in one or two branches of industry (e.g. the oil or car industry), so a global market rift involving one branch may result in significant changes in the ranking order in a short time. On the other hand, at the bottom of the list three-quarters of the differences in position are minimal.

[12] http://fortune.com/global500/list/ (March 2018)

order of over $100 billion there are 53 large companies and 58 countries. At over $50 billion companies comprise the majority (86 companies and 78 countries).

The interactive map included below indicates that the strongest companies are concentrated in three areas of the world: the USA, Western Europe, and Eastern Asia (Fig. 2.6).[13]

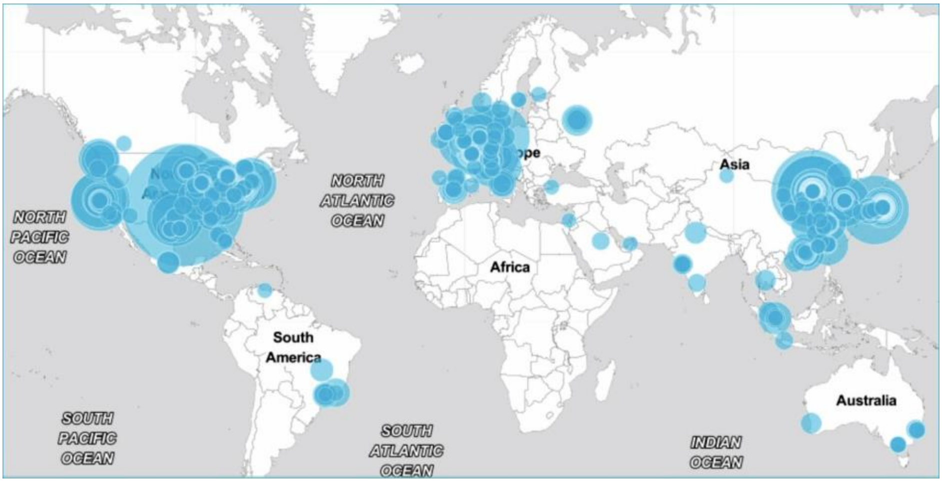

Fig. 2.6. Location of the world's 500 largest companies
(Source: based on fortune.com)
(Note: areas of circles are proportionate to company revenue)

In the case of multinational companies, what was originally *national capital* has become *international* due to mergers and international trading in shares (in which owners can hardly be identified). This international capital can take full advantage of national specificities: cheap labour, the shortcomings of environmental regulations, the ineffectiveness of trade unions, the weaknesses of consumer protection and social networks, and the reliance of certain governments on international financial institutions. By playing a role in modifying the disadvantageous elements of national regulations such as tax liabilities and duties, they often take advantage of markets, causing many small businesses to go bankrupt. Once such benefits are withdrawn, they relocate. An OECD survey revealed that while in the OECD countries company revenues grew faster than total GDP, the proportion of company taxes as a share of all taxes had not changed.

Despite the fact that today's multinational companies have considerable influence on national economies and societies, developing countries in

[13] For a more detailed territorial analysis, see http://fortune.com/global500/visualizations/?iid=recirc_g500landing-zone1

particular accuse them of being non-transparent, non-accountable, and able to obtain shadowy political capital from their economic power.

Concerning the globalising economy we encounter a paradox, however. Oddly enough, *the arch-enemy and threat to multinational capital which is considered the spearhead of globalisation is globalisation itself.* Large companies enjoy a favourable position as long as there exist nation states and borders between them and poor and vulnerable countries where citizens are content with a fraction of the wealth of richer societies, where concessions related to jurisdiction, health and social benefits can be won or there are environmental requirements that are much less stringent. These conditions enable such companies to deftly manoeuvre between regulations and to relocate. Our world is divided between globalisers and the globalised, where only with international cooperation (and more uniform national legislation) will the globalised have the chance to fight off the harmful effects of globalisation. The problem is that the advantages of globalisation are extremely attractive to outsiders in the short term, whilst long-term challenges are generally ignored. But life goes on, heightening tensions and the disproportionate situation.

As we have seen, there is an abundance of data proving the existence of globalisation. However, if we try to specify the *essence of globalisation*, we come across plenty of – often hardly compatible – conclusions about it which are all true in their own context. Here are three typical interpretations that seek to identify the essence of the phenomenon. One states that globalisation is nothing but a form of *global colonisation* in which money is used instead of arms. It happens almost voluntarily, meaning that those who are 'subjugated' often appreciate it, while the identity of the 'coloniser' remains unclear. Another interpretation describes it as the *aggressive dissemination of a consumer society culture*. Being imperfect humans, we do not object to consumerism. The third approach highlights *freedom of access*. We can access almost anything in any part of the world provided we have the money. Our actual situation determines which aspect of globalisation we feel is dominant, and helps us determine the truth of this list. Still, the bottom line is fixed: whatever you choose to call the process, you can't avoid it, even if you would like to. Imagine a situation – which is close to reality – that proves this. Natives living in the rainforests along the Amazon River have no knowledge about globalisation and have no intention of establishing contact with anyone. However, sooner or later they realise that the forest surrounding them is getting smaller and smaller, and (due to the inefficient protection of species) insects and game are disappearing, their rivers are lacking in fish (due to the water pollution of distant areas), and the tribe is developing mysterious diseases, although they haven't done anything 'wrong'. The sad truth is that, in reality, that such individuals are often massacred, too.

3. Recognizing global problems and the world models

For centuries nations and companies have ignored their harmful effects on the environment and lacked a global perspective. A peculiar exception is the geopolitical events related to World War II, namely the actual economic divide. Following World War II – and especially during the 1970s –, rapid economic progress and newly emerging globalisation drew attention to some phenomena that needed to be examined on a global scale, including *population growth* and associated *world food management*, the *limitations of* renewable and non-renewable *natural resources,* and the more obvious *environmental pollution*.

U Thant, Secretary-General of the United Nations, made a powerful speech about global thinking and action at a UN meeting in 1969: *'the Members of the United Nations have perhaps 10 years left in which to subordinate their ancient quarrels and launch a global partnership to curb the arms race, to improve the human environment, to defuse the population explosion and to supply the required momentum to development efforts. If such a global partnership is not forged within the next decade, then I very much fear that the problems I have mentioned will have reached such staggering proportions that they will be beyond our capacity to control.'* The extensive document that makes up the background material for the speech (*Problems of the human environment*)[14] provides a comprehensive evaluation of our planet's complex socio-environmental problems and sets forth several specific tasks. With its own tools, the UN took the leading position in the process, although it did not have sufficient political weight to carry them through. Its special body, UNESCO, launched the *Man and Biosphere* (MAB) program in 1970. In 1972, the first UN conference on the human environment was organised (See Chapter 16.1.1).

The global problems that were identified already appeared to be only superficially independent. Larger populations need more food and resources, and cause more pollution. This socio-environmental-economic correlation is indisputable, as is the fact that these fields require comprehensive analysis. It was suggested that adaptation to problems should become a core activity of mankind (i.e., learning and action). In the case of failure, we were told to expect major conflicts and a sequence of collapses. Although on a governance level

[14] The 66-page-long document can be accessed through the following link: http://repository.un.org/bitstream/handle/11176/295838/E_4667-EN.pdf?sequence=1&isAllowed=y

these concerns were cast aside, luckily professional groups realized the importance and complexity of these challenges. Also, the development of computer science offered assistance in unfolding the consequences. So it is hardly surprising that the years of the 1970s, especially the first half, were a golden age for the creation of world models.

The establishment of the Club of Rome in 1968 was an important event in respect of global thinking and world model creation. The organization was founded with the collaboration of independent philosophers. At the beginning, 30 scientists from ten countries were involved in the work. In the early 1990s the club included 70 professionals from 25 countries, with researchers representing various fields and cultures. According to their working method a team of experts undertook an analysis of a comprehensive topic, which was then discussed, and the summarized results were shared with the public. The team played a major role, particularly at the beginning of the process.

Relevant to the Club of Rome, the most influential and controversial world model was *The Limits to Growth*[15] from 1972, created by D. Meadows and his team. The more extensive book version of this was published in 1974 (Meadows et al.: *Dynamics of Growth in a finite World*). This model tried to forecast future events by using 99 global indexes[16] and empirical data from 1900–1970.

A great credit of the model is that it elaborates the possible effects of *environmental pollution* in spite of the fact that this was a neglected matter at the time. Environmental pollution rates and individual cost components were specified on the basis of countries' development status. The model even put forward cost estimates for eliminating forms of pollution. Concerning the evaluation of pollutants' effects on the environment, their natural dissemination and multistage effects on the ecological system were considered. For example,

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[15] Available from various sources, e.g.: http://www.donellameadows.org/wp-content/userfiles/Limits-to-Growth-digital-scan-version.pdf . The basic version of the model was worked out by professor J. Forrester who was involved in industrial modelling at MIT, and later edited for publication by his colleagues. (The radically new approach of the book made a very strong impression on the writer of the present book.)

[16] A few examples of the data that were used: concerning the area of population: population size, age composition, mortality rate, productivity, population density, efficiency of population control. *Industry*: industrial capital, investment rate, industrial production per capita, time period of use for industrial capital. *Food production:* area used for agriculture, size of usable areas, agricultural investment rate, average period of land use, land loss, number of agricultural jobs per hectare. *Environmental pollution:* extent of environment pollution, absorption time, time lag of the effects of environmental damages, yield in relation to environmental pollution. *Raw materials*: amount of non-renewable resources, rate of raw material use, raw material use per capita, rate of consumption.

the time lag of DDT accumulation was demonstrated. It is clearly visible (Fig. 3.1) that this poisonous material reaches its highest concentration in fish 11 years after maximum exposure. It was an important methodological decision that country borders and land borders were mainly ignored in terms of the spread of pollution, and models assumed global spreading; consequently, they proposed counter-measures at an international level. Experts did not have appropriate data and biological limit values for some types of pollution, but they incorporated them into the models, including them in a limited form.

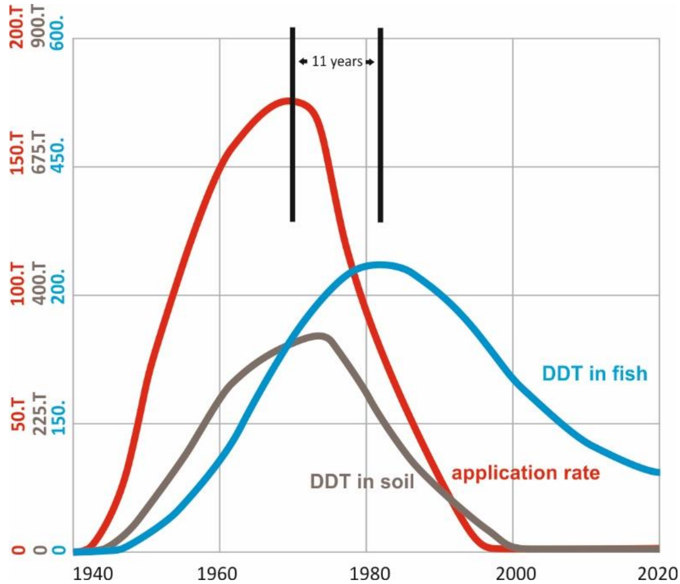

Fig.3.1. A*mount of DDT used annually, amount accumulated in the soil, amount accumulated in fish (Source: Meadows et al. 1974)*

A total of 12 models were created for the period 1900–2100, which can be divided into three main groups. The *standard* model with Versions 1 and 2 encapsulated the typical tendencies of the era (a growing world). *Limited economic growth,* Versions 3–7, foresaw that in some fields mankind would make attempts to mitigate adverse developments, such as population control. S*tabilisation attempts* (Versions 8–12) aimed to determine how to stabilise the quality of life of mankind. A grim future was predicted. The so-called *standard models,* based on the developments of the early 1970s, foresaw extremely serious problems arising in the middle of the twenty-first century which culminated in *drastic population decline*. Despite the various sets of conditions used in the models, the results were similar, and only the background reasons differed. For example, assuming known raw material deposits, raw material shortages, leads to depletion (Fig. 3.2a). Assuming a doubling of resources, environmental pollution is the main problem. The lesson to be learnt is that the *tendencies of the age cannot be sustained without endangering the existence of mankind,* and particular attention should be paid both to the amount and the process of utilization of resources. Models which involved regulation of only a few factors were not promising either (Fig. 3.2b). Stabilisation models assume the introduction of comprehensive regulation, and the most successful of these were those which counted on regulations being introduced as early as in 1975 (Fig. 3.2c), since any time loss involving differing stabilisation efforts, such as those starting from 2000 onwards, led to significant social conflict.

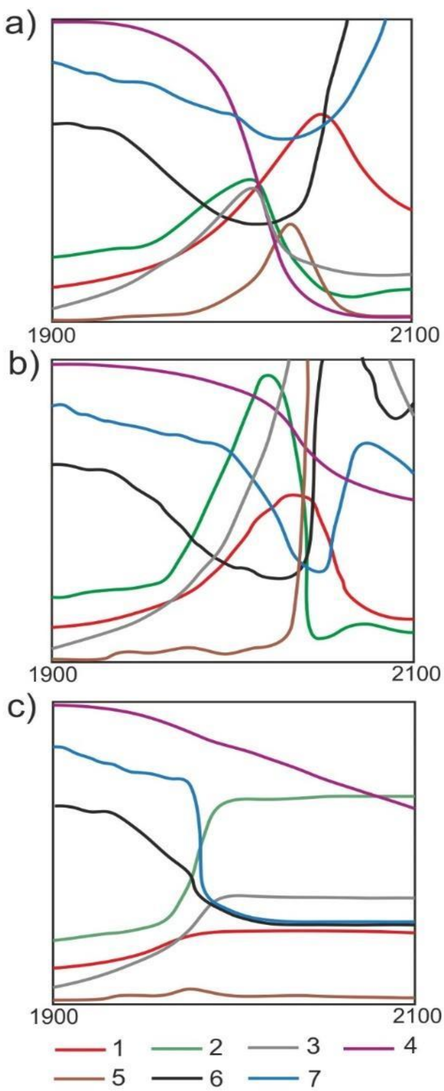

Fig. 3.2. Meadows models:
(a) world model, standard run (based on the trends of the 1970s);
(b) world model with ‘unlimited’ resources, pollution controls and increased agricultural productivity,
(c) stabilized world model

Legend:
1: population of Earth,
2: food per capita,
3: industrial production per capita,
4: raw material deposits,
5: environmental pollution,
6: mortality,
7: birth rate.

The report of the Club of Rome based on the Meadows models, but mainly the visions of the future, projected rather clearly, provoked heated reactions. Having zero economic development as the appointed economic, social and environmental ideological target was acceptable practically to nobody. This future was considered a capitalistic intrigue both by developing and socialist countries which feared be deprived of the possibility of economic progress. Neither was it welcomed by developed countries due to their internal inequality.

Beside the ideological attacks, the material received much relevant professional criticism. It is certainly true that it ignored regional differences (the relatively short time prevented experts from coming up with a more detailed analysis), it did not take sufficient account of the future role and significance of science, and it overlooked the threat of nuclear war that was hanging in the air. However, it had several merits:

- it set out possible alternatives using realistic data,
- its shocking results highlighted a real challenge: if mankind fails to take effective action, our planet will be unable to support its growing population,
- it made it clear that it is impossible to permanently sustain the processes of the age without serious consequences,
- it clearly communicated that a new, global way of thinking was necessary for effective solutions,
- it drew attention to the pressure of time, since the correct measures, if deferred, might be insufficient for dealing with the problems that were identified.

This was the first comprehensive, problem-raising, relationship-focused attempt at examining humanity’s impact. Its role and worth is indisputable. *It detonated thinking about global problems.* It should also be noted that, having accepted fairly raised professional criticism, the Club of Rome moved on to create many subsequent world models. The thus-initiated global thinking continued at five world model conferences between 1974 and 1977. We give here a brief summary of the key observations from the major models.

The second analysis of the Club of Rome, entitled *Mankind at the Turning Point* (editors: Mesarovič–Pestel, 1974) divided our planet into 10 regions and five levels (environmental, technological, demographic and economic, socio-political and individual). Its fundamental claim was that *crises related to issues such as population or environment are related to growth, but they are least likely to be stopped by restraining growth*. The document establishes that regional problem management may prevent simultaneous collapses, but that disaster can only be avoided by engaging in global thinking and action, and delay may be fatal as regards the rest of the choices. It poses global ethical questions (regarding famine, the use of resources, and responsibility towards future generations), as well as the threat of terrorism and nuclear wars.

The Argentinian Bariloche Foundation sought to find solutions to global problems from the perspective of developing countries. The related evaluation, called *The Bariloche World Model as an Infeasibility Study,* published in 1974, came up with a different approach, as its title suggests. The book version (Herrera: *Catastrophe or new society? A Latin-American World Model 1976*) provides brief answers in the form of responses to questions about our planet's future. It stated a belief that the main problem with the world models based on the extrapolation of current tendencies is that they tried to provide answers from the perspective of less developed regions. The underdeveloped regions at the time faced numerous real problems that were predicted to occur in the future by other models. Offered as a last resort, restraining economic progress to promote global balance would mean the conservation of inequalities. The analysis concluded that only with a new world order could disaster be prevented.

The Leontief model (Leointief: *The Future of the World Economy,* 1977) was prepared at the request of the UN and adjusted to its development strategy. This research is also worth mentioning for many reasons. It was based on a massive computer input-output analysis that examined more than 4000 variables linked to 15 regions and 45 professional subfields. From the perspective of the environment it is remarkable that it dealt with the economic effects of eliminating environmental pollution. In the case of economically developed countries, it incorporated costs adjusted to the environmental regulations of the USA. Least developed countries' objectives were more moderate, with lower costs, and in the case of the poorest ones it set aside such costs, as financial resources go on more immediate goals than environmental protection. This model, quite thoughtfully, was early to suggest a problem with the balance of payment of the worlds' countries and the debt crises that led many countries into economic crisis, though it greatly underestimated the magnitude of the issue. This model presents two ways out of the crisis that threatens mankind. The first is slowing down economic progress, while the second is creating a new global economic order, as also proposed by other models.

Related to the Club of Rome, three other comprehensive evaluations were published in the same era. *Reshaping the International Order* (Tinbergen 1976) reviewed almost the full inventory of social, economic and environmental problems, including population growth, famine, the arms race, deterioration in trade, the brain drain, environmental pollution, water shortages, etc. Showing the foresight of scientists, it is very interesting that in the different models several environmental challenges that only appeared in later years were mentioned. Although the book entitled *Beyond the Age of Waste* (Gábor–Colombo–King, 1976) focuses primarily on energy, raw materials, food and climate, it devotes special attention to waste (as indicated in the title) and two barely known problems: the ozone challenge (the ozone hole was discovered only in 1985), and the greenhouse effect. Another summary from 1976 led by László, entitled *Goals For Mankind,* established that social innovation is unavoidable and social planning is hardly separable from the development of world orders. Mounting problems can only be tackled by meeting new global objectives (e.g. arms-based security cannot be a future path), and global food and energy politics (growth using less energy and material) and world solidarity are required. The *obstacles mankind faces are not physical but internal, subjective boundaries.* Selfish aims sharpen and activate external borders, and global thinking may be hindered by the limitations of utilitarian, liberal democracies and religions.

Several models have subsequently been created to assess specific areas, although we will not address them now. Different world models have used different approaches. Although their results vary in many fields, they have something in common with the widely criticised Meadows models. They claim that the future of the planet requires global thinking and action, and the *tendencies of the present age cannot be sustained without endangering the existence of mankind.* Without global action, mankind will face a series of disasters.

Although the era of modelling came to an end in the 1970s, the Meadows model was updated in the early 1990s and in 2002.[17] It is true that the results provided more details, and new aspects were taken into account (e.g. the ecological footprint), but the key message did not change. Although mankind has made a lot of effort, there have been no substantive changes.

In 2005 Dennis Meadows gave a presentation in Hungary during which he pointed out the two options we have. Either we face total collapse, or we take decisive steps to increase sustainability. The author of the present book asked him if we needed to wait until a comprehensive disaster occurred before mankind would act together. Meadows gave an evasive answer, but the eighth slide of his presentation spoke louder than words: 'Practice bracing for a collision!'.

[17] Limits to Growth: The 30-Year Update

II. Our global environmental problems

Today, if one tried to look up humanity's most important environmental issues on the internet, they would find at least 15-20 significant problems. These include problems that, although they are listed individually, are strongly related to each other (for example: overpopulation – urban growth; climate change – global warming; air pollution – acid rain; the ozone problem, etc.). In this book, within its limits, we elaborate on these issues, although there are problems concerning several of them.

It can also be observed that the importance of an issue is influenced by historical events, both in terms of how it is ranked by individuals and in the press. This is well represented by the fact that although in the period following the power plant accident of Fukushima in 2011 there was high-level international concern regarding the use of nuclear power (as there was following the Chernobyl incident), this environmental threat was only occasionally being mentioned at the beginning of 2018. In the period between *1950 and 1980, the issue of hunger was probably the most alarming one. Later, it was acid rain, then the appearance of the ozone hole and, in latter decades, the issues of climate change and fresh water shortages give us reason to be concerned when we look to the future. In this book we begin with the three issues deemed most important by the author (overpopulation, climate change, and water-related issues) and also discuss matters thematically related to the same topics.*

4. Overpopulation and other issues related to population

4.1. Population growth

For a long time, the population of the world changed very slowly. According to estimates, in the period before the present era the population of our planet doubled every 2-3 thousand years (with an estimated population of 160-180 million people at the time of the Roman Empire), and this number changed very slowly until the seventeenth century (it took approximately nine hundred years for the population to double from the beginning of our era, then seven hundred years for the next doubling). This annual growth rate of below 0.1% started to rise in the seventeenth century and the population had reached one billion by 1800. From the beginning of the twentieth century the rate of growth started to accelerate and, following World War II, it virtually exploded (see Fig. 4.1), while in the 1970s the population increased by one billion in only 12-13 years (Fig. 4.2).

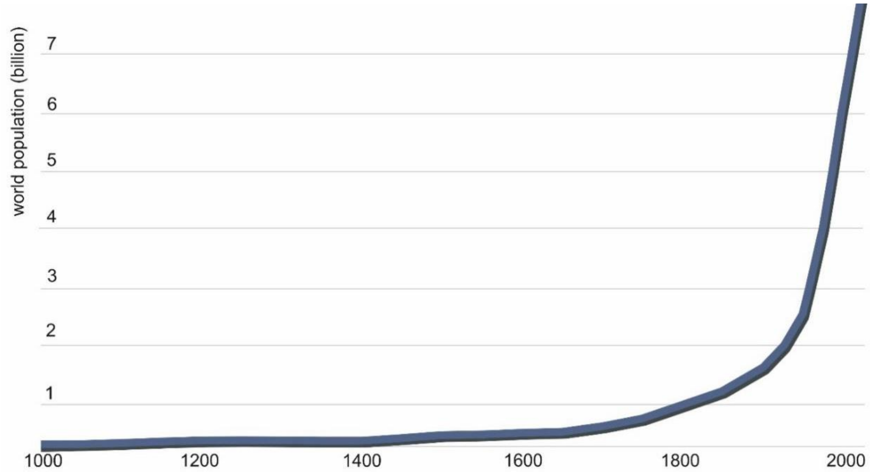

Fig. 4.1. Growth of global population between 1000–2018 (billion people) (Source: Worldometer)

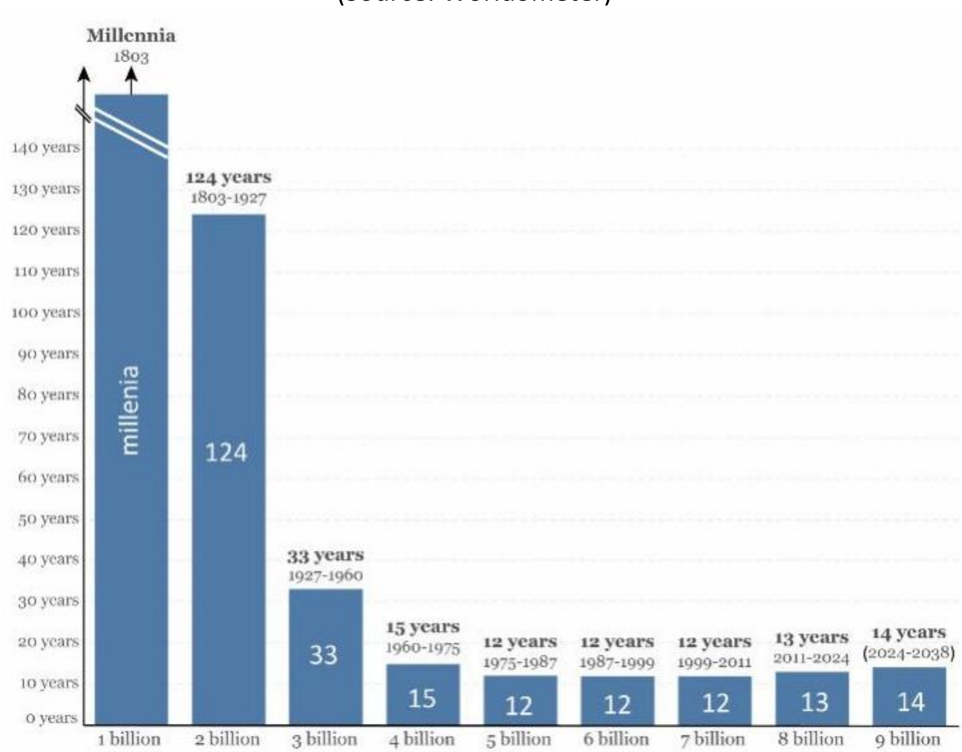

Fig. 4.2. Time necessary for global population to increase by one billion (Source: based on OurWorldinData)

Looking at the reasons for such incredibly fast population growth, we find several factors that are mutually reinforcing. In a book, Harari (2015) specifies three main reasons: the decrease in hunger, epidemics, and wars. This, however, does not mean that these causes of death will cease in the upcoming decades, but their effects on the population will be less and less significant.

Medical science has developed greatly in the past century, and especially in the past few decades. The Spanish Flu caused 50-100 million deaths in 1918 (significantly more than the approximately sixteen million fatalities of World War I), while thirty-five million people had passed away by 2016 due to AIDS, the dreaded disease that appeared in the 1980s (although the virus is more or less treatable today), and fifteen million people were infected and two million killed by the smallpox epidemic in 1967, which by 1979 had been successfully tackled worldwide. As a result of SARS (atypical pneumonia) that fearfully arose in 2003, less than a thousand people ultimately died. The Ebola virus (classified as the most severe public health emergency of modern times by the WHO) reappeared in 2014 and caused the deaths of fourteen thousand people, but was finally tackled by 2016. Medicine has also delivered great results in terms of reducing infant mortality. In 1800, 43% of all children died before reaching the age of five, while by 2015 this proportion had been reduced to 4.4%.

In the 1950-1960s, the ability to supply a quickly growing population with food seemed to be uncertain. In the Great Chinese Famines, twenty-five million people died of hunger in 1907 alone, and 15-43 million more between 1958 and 1961. Famines that caused the death of several million people were also frequent in previous decades.[18] It is no coincidence that a predicted shortage of food and the related famines were also the global problems that threatened humanity the most in the different world models. The fact that Vester, who belonged to the Club of Rome, claimed in a book[19] that the carrying capacity of Earth was two billion people living at the level of the average USA citizen clearly describes the situation that existed at that time – although four billion people were already living on our planet then. Until the beginning of the 1970s, it was mostly high-population, low-income countries (China, India, Bangladesh, etc.) and the Sub-Saharan region that were exposed to the problem of hunger. Making use of the favourable effects of globalisation, even the situation of areas poorly supplied with food has increased (due to the impact of the green revolution, immigration, and food imports). The opportunities created by global transportation systems (rapid food aid) mean that periods of hunger do not

[18] According to current statistics, there have been at least twenty famines that caused the death of more than a million people. Sixteen of them took place during the nineteenth and the twentieth century.

[19] *Unsere Welt, ein vernetztes System* / Our world, an Interconnected System, 1978.

inevitably result in deaths. Instances of hunger and malnutrition still occur, but they have decreased significantly. In spite of this, in 2015 almost eight hundred million people still did not have access to sufficient food, primarily in Africa and some countries in Southern Asia.[20]

In the past decade, the impact of *wars* on the population has decreased both in terms of proportion and absolute number of deaths.[21] (As mentioned before, for example, fewer people died during the four years of World War I than perished in approximately one year due to an epidemic.)

Due to the favourable changes that have generally positively impacted the life expectancy of the population, life expectancy, and especially the productive age of humans, has been significantly extended. The average global life expectancy of thirty-two years in 1800 had increased to forty-eight by 1950, and to seventy by 2012. The great increase in life expectancy experienced in the past half century (Fig. 4.3[22]) has played a dominant role in the dynamic growth of the population – and not only today, but it will also continue to in the coming decades. The aforementioned figure clearly displays the fact that in 1800 people did not live to more than forty years old, even in the most developed regions of the world. This increased to seventy years in one and a half centuries, while overall the life expectancy of approximately 40% of the population increased by twenty-five years, although in the case of half of the population it only grew by ten years. However, in the past half century, along with the increase in life expectancy, many significant changes have taken place: in developed countries, life expectancy has increased on average by 'only' ten years, while in poorer regions the figure is 25-30 years. This means that the difference between countries in terms of development has decreased significantly. The figure also shows that the situation of some countries has undergone great change in the last two hundred years. For example, both South Korea and Spain have moved from the group of countries with the lowest life expectancy into the group of those with the highest. China has also improved its situation greatly, India has experienced some changes, while the favourable position of the USA has hardly changed, for example.

[20] http://www.globalhungerindex.org/pdf/en/2017/posters.pdf GHI values were determined based on the proportion of the undernourished population, the average age of the population (also referring to food supply) and body size, state of health and the mortality rate of the population below the age of five.

[21] For a more detailed figure, see: https://ourworldindata.org/war-and-peace

[22] A detailed version is available in Chapter 1.4 of https://ourworldindata.org/life-expectancy .

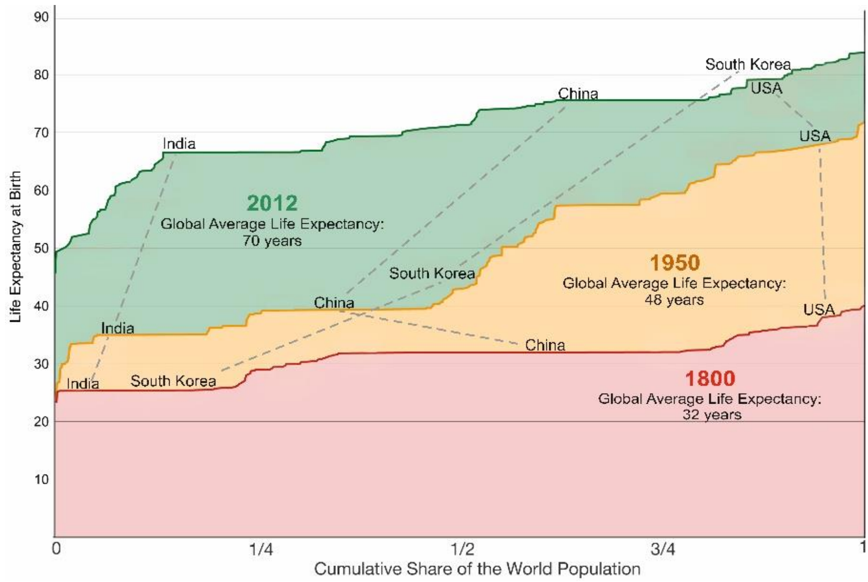

Fig. 4.3. Changes in life expectancy of the world's population over the past two centuries (simplified, based on a figure from OurWorldinData).

However, new factors have arisen amongst the causes of early death. A summary pertaining to 2012 states that from the fifty-six million deaths, 620 000 were due to violence (120 000 due to war, 500 000 due to criminal acts), besides the 800 000 suicides and 1.5 million deaths caused by diabetes. *Instead of hunger, obesity and 'overnutrition' have emerged as the main causes of death.* Traffic accidents are also ranked highly on the list of causes of death: they number over one million in the past two decades. In 2016, 1.34 million people died due to traffic accidents, of which 151 000 in India, and 58 000 in China. These two highly populated countries are changing in different directions in this regard: while in China the situation is getting better and better (in 2004, 107 000 deaths were caused by traffic accidents), in India the situation is continually deteriorating (in 2000, 79 000 people died due to traffic accidents). On a global basis, approximately the same number of people die due to fire-related accidents as those who die due to war (132 000 people in 2016).

One of the proposals for intervention in the Meadows' models was population control. The most populated Asian countries have tried to take action along these lines. In India, during the state of emergency in 1965 approximately 6.2 million underprivileged men were sterilised forcibly (two thousand people died due to the operation), fifteen times more than those subject to the procedure by the Nazis. The fall of the government ended these violent interventions. Since the 1970s, sterilisation has mainly been performed on women. During 2013 and 2014, approximately four million women were sterilised.

In China, *the one child per family* policy started in 1979. The government made people comply with the policy by means of strict central controls, penalties (even taking half of a family's income), and discounts. From the beginning of the 1980s, a sterilisation programme was also in operation (e.g. in the case of families with two children). The enforcement of the programme faced many difficulties (fraud by officials, cheating) and did not involve minorities. As a compromise, families who lived in the countryside were allowed to have a second child if their first one was a girl. According to estimates, more than one-third of the population was affected by the stricter rules, and half of the population by 'lighter' regulations. According to certain sources, four hundred million children were not born due to this programme. If one goes to China, one can quite quickly see the results of this population policy on the streets. The author of this book was petrified to note the absence of children in 2006. On a sunny Sunday morning (the rain had washed out the smog from the air the previous day), the largest park in Beijing was full of families whiling away their free time. Generally, families tend to go to such events together, yet hardly any children could be seen (Fig. 4.4).

Fig. 4.4. Sunday in a popular park in Beijing – almost completely without children (Author's photo, 2006)

The one-child policy, besides decreasing the growth of the population, brought about numerous negative effects. The one-child model can definitely be seen on the population pyramid (Fig. 4.5) of the country, as can the 'surplus' of approximately thirty million men from the younger generations (exploiting the opportunity provided by modern medicine, families tended to choose boys). The numerical relationship between those who earn money and those who depend on others has also deteriorated a lot. The fact, however, that the living standards of families has increased significantly by not having children contributes greatly to the acceptance of this policy in society. However, recognising the unfavourable processes, birth control was basically discontinued in 2015.

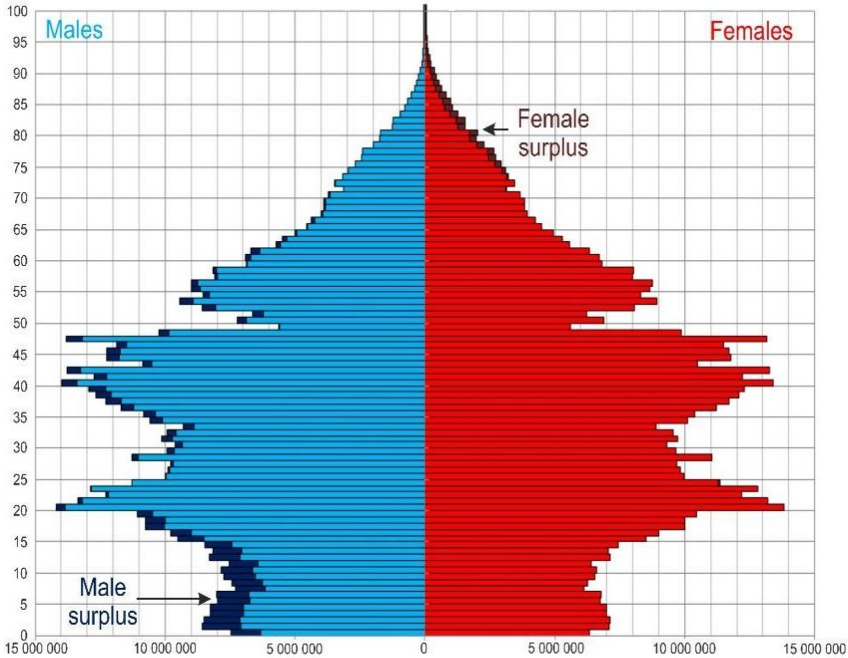

Fig. 4.5. Population pyramid for China broken down to years based on the census of 2010.[23]

The chart of population growth of the most populated countries clearly displays the fact (Fig. 4.6.) that the population boom in China and India (which already had a massive population) has accelerated since the beginning of the 1950s. Although this boom resulted in mass deaths due to hunger, this hardly can be seen in the data plot. However, the previous population pyramid shows that famines have primarily affected children. It can also be seen that the drastic population growth control programme in China has hardly affected the growth of the population, as due to better living standards, people tend to live longer.

A more humane population control programme was implemented in *Indonesia* (the fourth most populated country in the world) and involved the promotion of a two-child model, relying primarily on effective propaganda and social awareness.

[23] Source of the figure: http://www.visualcapitalist.com/the-chinese-growth-engine-is-sputtering/ The tragic famine at the end of the 1950s can be seen in the figure.

The *two children is enough* programme was promoted by countless means, such as the typical billboards placed on the side of roads, with mixed results. The more educated population in Indonesian cities accepted the programme but, moving further away from the cities, the number of births only increased in reality. Regardless of this, Indonesia and Thailand are considered countries where population control was implemented without causing significant tension in society.

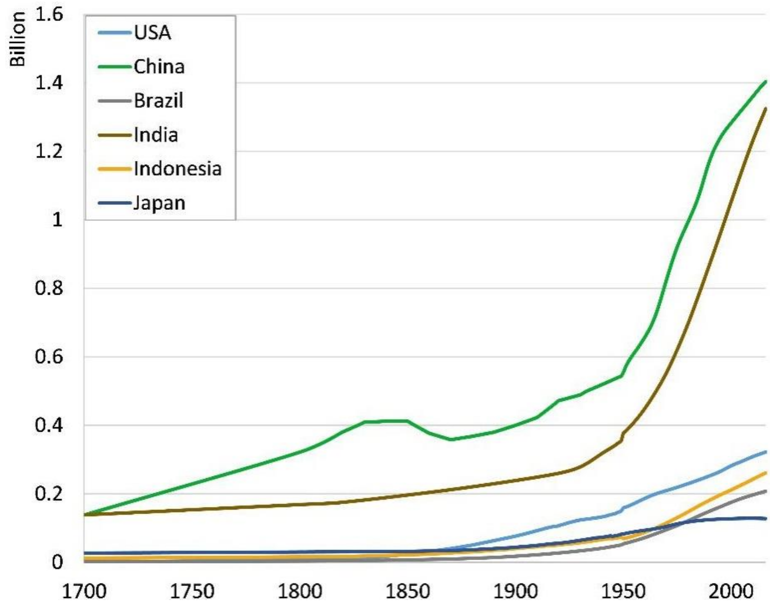

Fig. 4.6. Change in population of the most populated countries (1700–2015) (Original source of data: UNDP. Chart prepared with OurWorldinData).

In *Japan,* the mitigation of the rate of population growth was a result of development. Along with the great economic development that took place after World War II, the country also went through significant social change that affected the population at its essence, and today's demographic trends in Japan are quite similar to those of Western Europe.

Many developing countries try to stop population growth using violent means. Humanitarian aid (from developed countries) is often conditioned on the reduction of birth rates, therefore forced sterilisations and forced abortions are quite common – in some countries, this is sometimes the only service available within the framework of free health care.

The majority of the countries that face population-related issues have done nothing, or hardly anything, to resolve the issues resulting in further population growth. It is true, however, that the majority of these countries have failed to take measures due to reasons other than their helplessness. My opinion is that, before judging them, we should look at the situation from their perspective. These countries claim that individuals who live in developed countries have far better living standards than a hundred years ago, although there are far more people now than at that time. According to this analogy, a larger yet well organised population can lead a better life. They also cite evidence that land previously classified as infertile can now be cultivated economically with proper agro-technical means (and significant capital investment). The question is whether they can find the people they need to support their position.

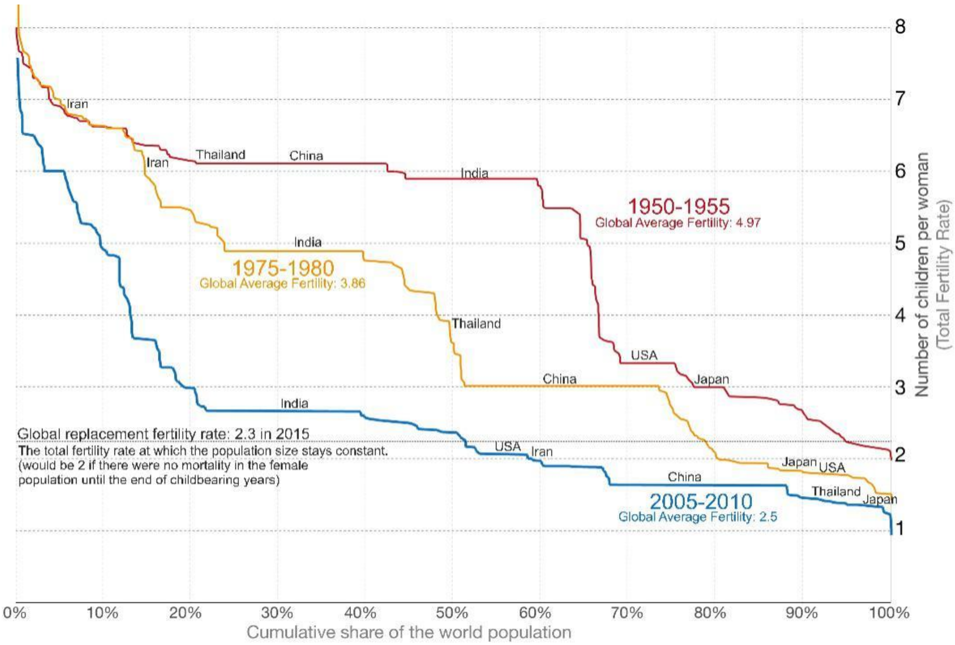

Fig. 4.7. Number of children per woman in the world (fertility rate) (1950–2010) (simplified based on a chart from OurWorldinData[24]).

As a result of economic growth, far greater awareness (due to the spread of TV and internet, as described earlier) and aggressive means of population control, the fertility rate for women has decreased significantly, having affecting three-quarters of the population (it has declined from 5 to 2.5). While at the beginning of the 1950s for 60% of the global female population one women would have delivered six children, at the end of the 2000s the number had declined to below 2.5 for three-quarters of the world (Fig. 4.7). In China, the number is now 1.6, and in India it has dropped to 2.6. The change in social awareness is also indicated by the fact that, in the past few decades, the birth rate per woman has decreased from six to below three within a short time in several countries with a large population, besides those mentioned previously:

[24] See detailed chart: https://ourworldindata.org/fertility-rate

this took less than ten years in Iran (1986–1996), 18 years in South-Korea (1960–1978), and twenty years in Bangladesh (1982–2002).

The average age of the world's population is thirty years old in 2018, meaning that despite the significantly decreasing birth rate (as experienced in the majority of the world in the past few decades), the population will grow significantly in the future (Table 4.1).

Table 4.1. Population characteristics of the world by large regions, January 2018 (Source: worldometers.info)

Region	Population (million)	Yearly change (%)	Yearly net change (million)	Density (P/km²)	Fert. rate	Med. age (years)	Urban population (%)
Asia	4,545,133	0.9	40,705	146	2.21	30	49.6
Africa	1,287,921	2.52	31,652	43	4.71	19	40.6
Europe	742,648	0.08	574	34	1.61	42	74.3
Latin America and the Caribbean	652,012	0.99	6,418	32	2.11	29	80.2
Northern America	363,844	0.73	2,636	20	1.91	38	83.5
Oceania and Australia	41,261	1.39	570	5	2.41	33	70.3

4.2. Demographic division of the world

After World War II, the countries of the world were categorised either as 'developed' or 'developing' (approximately one-fifth qualified as developed), and it was relatively easy to draw a geographical line between the two groups. For some time, the difference in economic development also showed in demographic terms: developed countries whose population was growing slowly or not growing at all were on one side (with continuously increasing living standards), and countries with fast population growth and with stagnating or deteriorating living standards were on the other. In the middle of the 1970s, approximately 2.3 billion people were living in regions with slow population growth (with an average growth rate of 0.8%) and approximately 2.6 billion people were living in regions that were growing intensively in terms of population (over 2.2 billion all across regions). There was almost no overlap between the groups.

Since the 1980s, this line that divided the world into two from an economic point of view has become more complicated in a geographical sense. Due to the boom in the price of raw materials, several other previously underdeveloped countries have suddenly moved into the category of 'developed' countries (if they used their great income from oil wisely). Attempts at population control started in different countries, and more rapid economic growth changed the previously established population patterns, resulting in demographic changes in many countries (as can be seen in the previous chapter). All in all however, the population ratios between the countries of different development significantly changed due to the different population rate (Fig. 4.8) and today, at least ¾ of the population lives in the less developed regions. The two groups not only differ in terms of size, but also in terms of geographic structure (Fig. 4.9.)[25]. The younger population is smaller in developed regions, which may pose problems in the sustainability of society in the future. However, in less developed regions, the more and more continuously shrinking generation of earners is required to support both the far more populous young, and the far longer living elderly population.

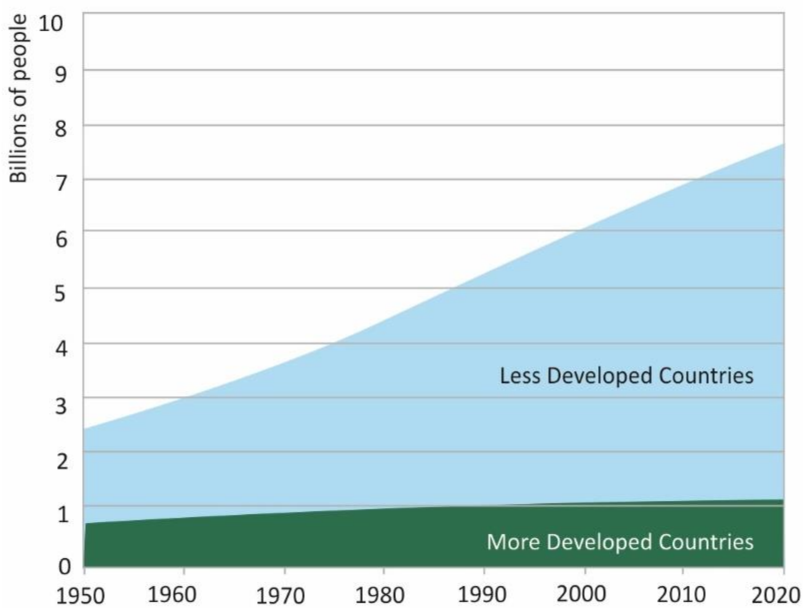

Fig. 4.8. Change in population in developed and less developed regions (1950–2020) (Source: UNPD)

[25] If you are interested in the division of the population of particular countries or groups of countries, please visit: https://esa.un.org/unpd/wpp/Graphs/DemographicProfiles/ .

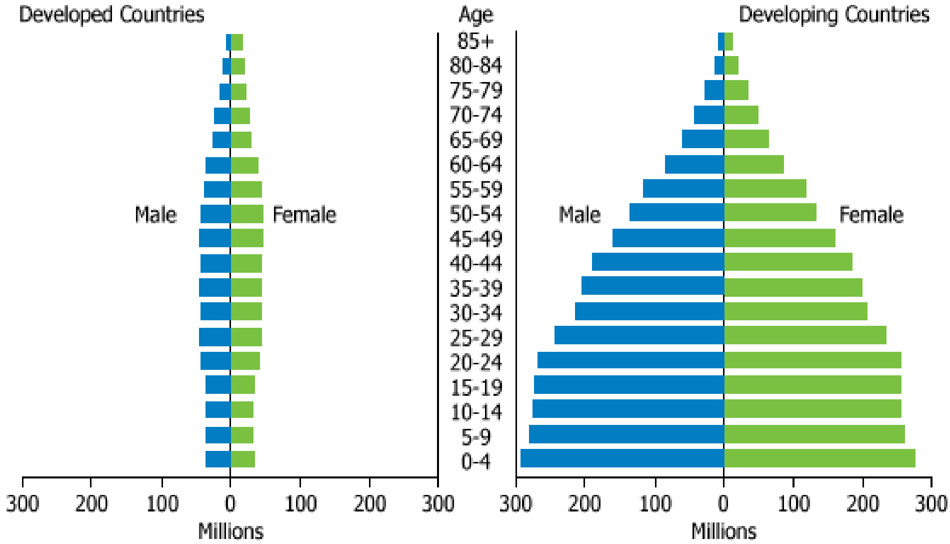

Fig. 4.9. Population pyramid of developed and less developed countries in 2010. (Source: UNPD 2011)

4.3. Urban and metropolitan growth

Changes in population and the territorial distribution of the same can cause problems even within one country. For a long time, we considered the growth of the urban population to be a favourable and natural process that accompanied social development. This approach, although it has been modified in the past few years to some extent, is acceptable if urban growth takes place in coordination with social and economic processes. However, the urban growth that is taking place in developing countries can hardly be considered a standard process. Between 1920 and 1985, the urban population of developing countries grew nearly tenfold, (from one hundred million to one billion), and by 2015, it had almost reached three billion. However, this process has not yet reached its end. In terms of the total global population, the urban population has exceeded the 50% threshold since 2008, and in 2018 the proportion was already 54.9%. Urban growth in some regions is still significant – for example, in Africa it was 40.6%, and 49.6% in Asia (Fig. 4.10). In terms of a territorial comparison of continents, it might be of interest that Latin America has overtaken Europe in the process of urbanisation since 1990, and that Oceania as a region has stagnated since 1970. Naturally, there are significant differences within the particular continents, mainly influenced by historical economic and environmental differences.

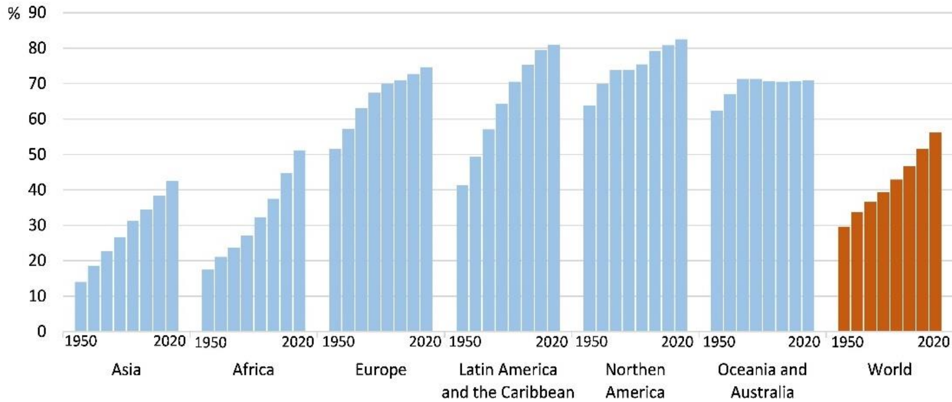

Fig. 4.10. The rate of urban growth across the world
(Source of data: WUP 2015)

In parallel with urban growth, metropolitan growth is also taking place. In 1940, 1% of the world's population lived in a city with a population of over one million; in 1980, it was every tenth person, while in 2000 every sixth person lived in city with a population of over a million people. In 2016, the number of cities with a population of over a million people was five hundred and twelve, and there were thirty-one cities with a population of over ten million, twenty-three of which were cities in countries previously considered less developed. In 1950, the population of the most populated city, New York, was 12.3 million. In 2016, the population of Los Angeles, now ranked 21st on the list, equalled this number. In 2016, the population of eight cities exceeded twenty million (in descending order: Tokyo thirty-eight million, Delhi twenty-six million, Shanghai twenty-four million).[26] This metropolitan growth is unstoppable, because as of 2018, 24.5% of the population were in cities with a population over a million people, and 12.7% in cities with a population over 5 million people (Fig. 4.11).

However, the problem lies not with urban and metropolitan growth, but with the often insufficient conditions that accompany this. There is no historical parallel to the process of urbanisation that is taking place in developing countries. The rate of population growth witnessed by developed Western metropolises within a century is being achieved by the metropolises of the developing countries within a lifetime. The result of this is that some parts of the metropolises that were previously the engines of development cannot develop their infrastructure at the necessary speed, and cannot maintain the quality of urban services. In many places there is not enough mains water, there are no hygienic toilets, sewage systems are

[26] Detailed statistics about urbanisation processes are available in the volume *World Urbanization Prospect- 2014 Revision*:
https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf

incomplete, there are significant problems with transportation, waste removal services are partial, and waste depots pose a significant environmental threat. In many African countries, (but also in India and Indonesia in Asia), some of the urban population is required to defecate outdoors (open defecation). According to a survey conducted in 2015, less than one-third of the current 1.2 billion population of India use a toilet, and more than 186 000 children under the age of five die due to diseases related to diarrhea each year. The importance of the problem (Fig. 4.12) is also shown by the fact that since 2003 a Toilet World Conference has been organised every year, and, for example, the construction of many million toilets is repeatedly promised by politicians in India. In 2015, the government of India set 2019 as a deadline by which each and every household must be provided with a toilet. Although the situation has improved in many countries of the world (we can also see this on the interactive maps[27]), those who live in the countryside are more exposed to this problem.

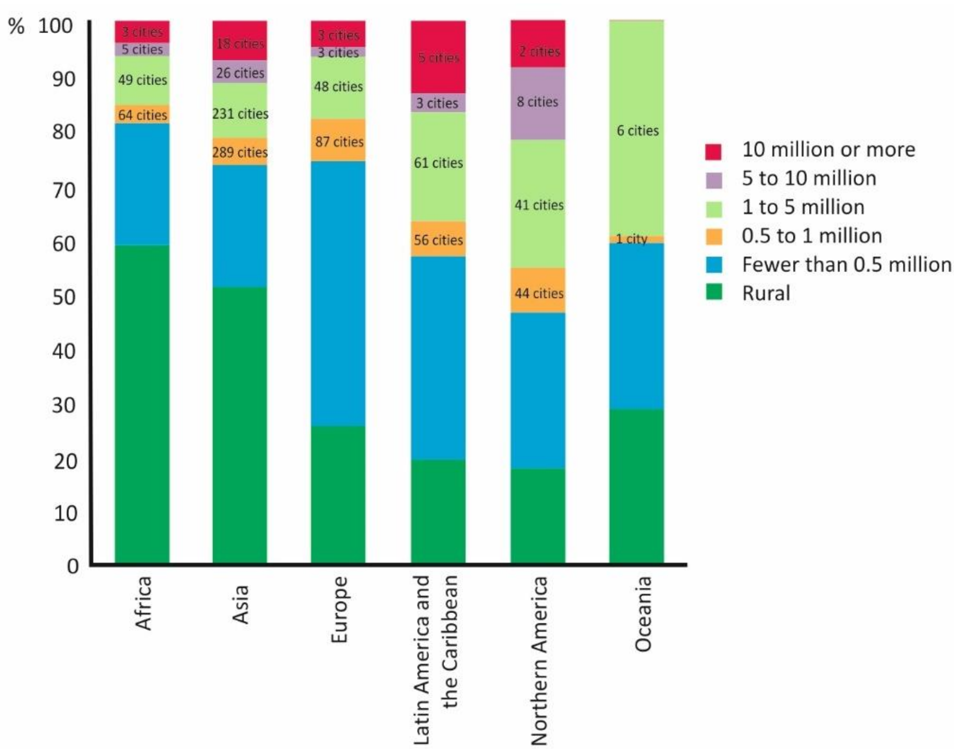

Fig. 4.11. Distribution of population based on the size of cities in 2016 (Source: adapted from UN DESA 2016)

[27] At https://ourworldindata.org/water-access-resources-sanitation it is possible to change the time scale of the figures between 1995 and 2015 in Chapter I.10.

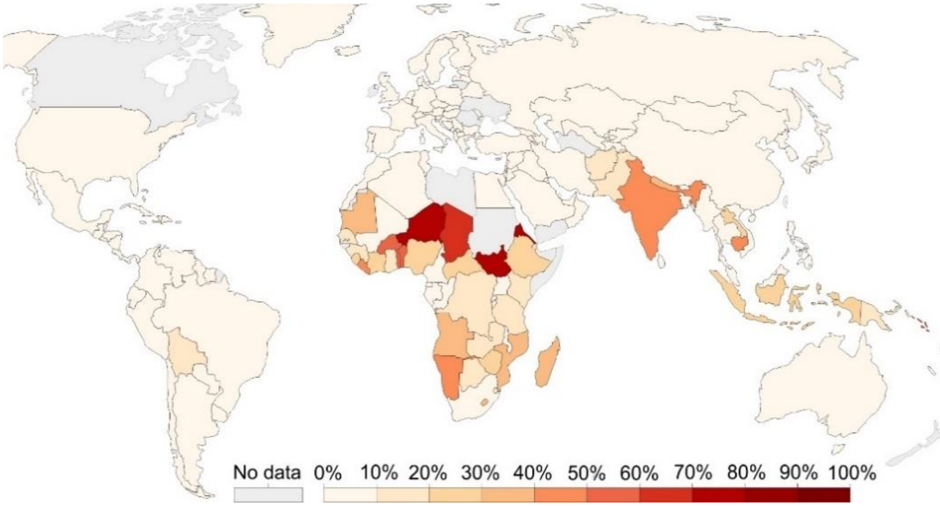

Fig. 4.12. The proportion of people practising open defecation in the countries of the world 2015 (%) (Source: based on a figure from OurWorldinData)

Air pollution also poses a significant problem in the metropolises of less developed regions (we will look into this issue in detail in Chapter 5.5). Metropolitan growth not only damages cities, but also their environment. For example, after the energy price boom of 1980, the forest resources within a hundred kilometres of the nine largest cities in India decreased drastically (by 15–60%) due to the population returning to the use of firewood.

There is no end to the unfavourable phenomena. The accelerated growth of the cities in developing countries can be traced back to several reasons. Escaping to the city due to high natural procreation and economic difficulties are amongst the reasons that can be explained. Unfortunately, however, many times the interested governments also almost encouraged the process out of politics and prestige, not recognising trouble in due time. For example, Sao Paolo has been prioritised in terms of state subsidies in the past 100 years, this is how it could happen that although only 10% of Brazil lived there at the beginning of the 1980s, 44% of electric energy was used in the city and half of industrial production and workplaces also concentrated there.

Governments of the developing countries have often favoured metropolises rather than the countryside. Excessive urban growth has often generated disproportionately high costs in these countries that face economic problems. A more reasonable division of resources would be advantageous both in terms of the economies and the environment. China can be mentioned as a good example of how the growth of cities can be slowed with restrictions on immigration, while at the same time policy makers acted to bring up salaries in villages and cities to the same level through a process of agricultural investment and large-scale agrarian reform. Although the Chinese example cannot be copied everywhere, it may be a good example of effective government intervention.

4.4. Growing income equality between people

Although with the economic development of our world, the proportion of those suffering from hunger has decreased, their absolute number has not dropped significantly (the number of people suffering from hunger decreased by two hundred million in twenty-five years, although 795 million people were still undernourished). However, the number of people living in extreme poverty[28] has decreased significantly both in number and proportion (Fig. 4.13). At the beginning of the nineteenth century, more than nine-tenths of the population lived in extreme poverty, and this rate was still 72% in 1950. However, the proportion slowly decreased to 29% by 2000, and to 9.6% by 2015.

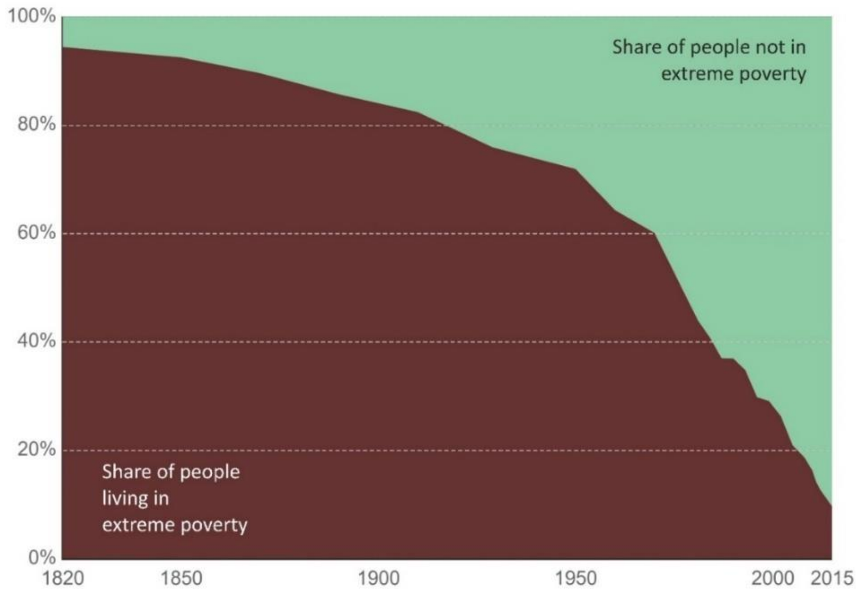

Fig. 4.13. Change in the proportion of people living in extreme poverty in the world between 1820 and 2015 (%). (Source of data, Worldbank; the illustration was constructed based on the figure at OurWorldinData).

It is a strange contrast that, alongside hunger, humanity is increasingly obese. In North America and Europe, more than a quarter of the population were obese in the last 10 years, but this proportion also exceeded 10% in Africa

[28] Researchers define extreme poverty as living on less than 1.90$ per day.

(the continent most exposed to hunger) in the past few years, and the proportion is steadily growing on all continents (Fig. 4.14). Men are obese mostly in the USA, but women are not only fatter in a global sense in North Africa, in the Middle-East and South America, but are affected by obesity 5–15% more than men (Fig. 4.15).[29]

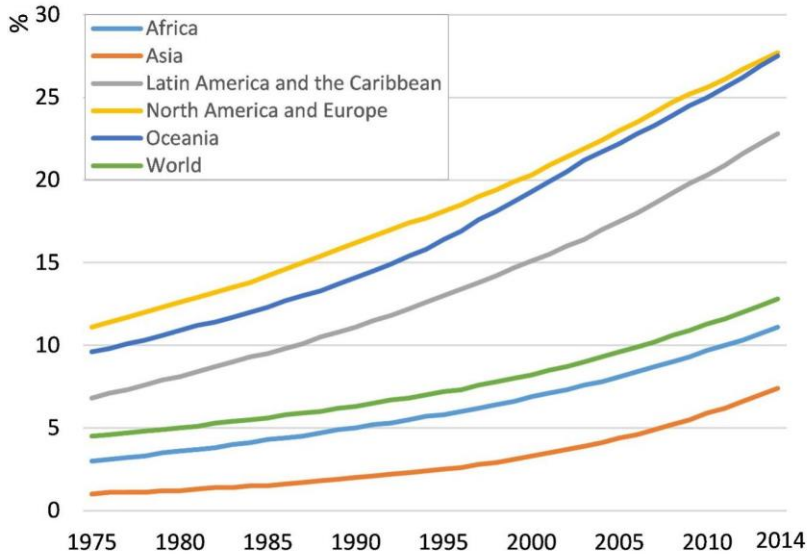

Fig. 4.14. Proportion of obese population per continent 1975–2014 (%) (Source of data: FAO; the illustration was constructed based on the figure at OurWorldinData)

The gap between individual incomes is increasing enormously. *Oxfam International,* an organisation that works to eliminate poverty, has prepared analyses of the income relations between the richest and the poorest. In 2016, the organisation reported that the sixty-one richest people in the world had double the wealth of half of the poorest in society. However, detailed analyses have revealed in the meantime that the assets of the poorest stratum of society have been significantly overestimated (while the assets of richer people can be tracked). As a result, it has been established that at the beginning of 2017 *the wealth of the eight richest people in the world equalled the total wealth of the 3.6 billion poorest people*. In only 2017, the five hundred most wealthy people increased their wealth by more than one trillion dollars (almost 25%).

[29] We can monitor changes between 1975 and 2014 on the interactive map at https://ourworldindata.org/obesity , even separately by gender.

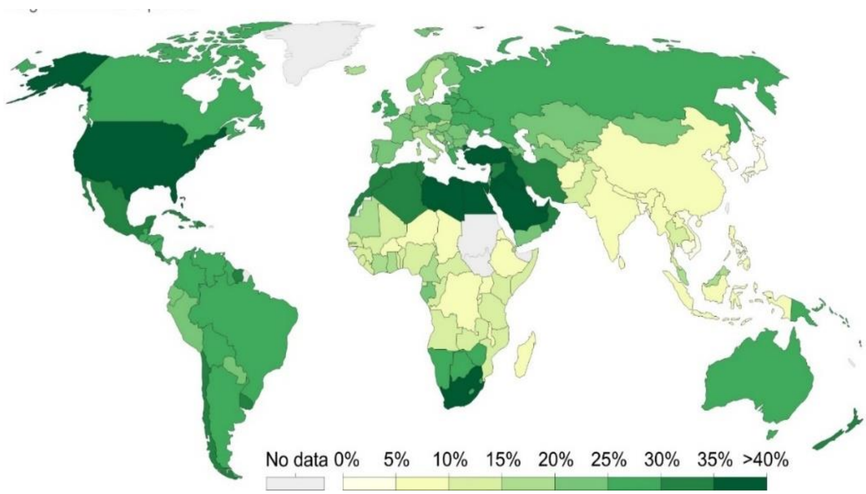

Fig. 4.15 Obesity in the female population in the world in 2016 (analysis by Ritchie and Roser 2017; the illustration was constructed based on the figure at OurWorldinData)

The most important findings, complementing those mentioned before, of the Oxfam report of January 2017 (Briefing paper)[30] are the following. Seventy percent of humanity live in countries in which inequalities have grown in the past thirty years. Between 1988 and 2011, the income of the poorest 10% increased by only $65 per person, while the income of the richest 1% increased by $11800. In 2016, the wealth that was generated enriched only the richest 1%, and the poorer half of the population received nothing. In the next twenty years, five hundred rich people are expected to leave 2.1 trillion dollars to their descendants, which is almost the same amount as the current GDP of India. According to another analysis, the income of the poorer half of the population of the world has not changed in the past thirty years, while the 1% with the highest income have tripled their incomes.

The photo of the publication already mentioned before (on Page 52, *Overdevelopment*, *Overpopulation*,..[31]) also accurately illustrates the difference in the living standards of the world's population. A poorer part of Sao Paolo (but not a slum) is separated from the high-rise housing estate of the rich by a wall, beyond which there are swimming pools and green areas on all the balconies, and sports fields and pools between the houses.

[30] https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/bp-economy-for-99-percent-160117-en.pdf

[31] We hereby provide the link to the publication once again: https://populationspeakout.org/the-book/view-book/

4.5. Infectious diseases, epidemics

As we have already pointed out, the reduction in epidemics was a basic factor in the acceleration of population growth. However, although epidemics have died down, they have not been eliminated. We tend to notice them most when they arise and become media sensations. Day-to-day attention is mostly focused on wars, acts of terrorism, and traffic accidents, although AIDS and malaria cause more deaths individually than all of the latter combined.

The epidemic-like appearance of *AIDS* started at the beginning of the 1980s and had already caused 300 thousand deaths by 1990. The number of new infections reached its peak in around 1997 and the number of deaths around 2005-2006, when almost two million people died due to the disease each year, but it also caused more than one million deaths in 2016 (Fig. 4.16). Owing to effective awareness-raising, the epidemic is dying out and medical developments mean that the majority of sick people do not now die of the disease but can live in humane circumstances. The previously lethal disease had infected approximately seventy-six million people by 2016, and approximately thirty-five million people died as a result of it. AIDS mostly affects the Sub-Saharan countries of Africa (the most southerly countries of the continent) where more than 10% of the adult population is affected (in 2015, 22.2% of Botswana, and 19.2% of the Republic of South Africa). Unfortunately, there is still a high number of new infections in the Republic of South Africa and highly populated Nigeria (over 380 000 and 250 000 each year, respectively). As a result of the deaths caused by the epidemic, the population pyramid of Botswana (the population of which is otherwise growing rapidly) indicates that up to 100 000 - 130 000 people are missing per generation (five-year intervals are illustrated on the figure), and the average life expectancy of the generation born around 2000 has decreased by approximately 15-20 years (Fig. 4.17 and 4.18).

Malaria is a 'traditional' endemic disease of tropical regions, causing tens or hundreds of millions infections a year. By prevention (mosquito control) and use of medicine, the disease can be cured quite effectively. Although the number of deaths is scaling down, malaria is still responsible for the death of hundreds of thousands each year. In 2000, approximately 840 000 people died due to the disease, mainly in central Africa. By 2016, the number of deaths had decreased to 720 000 (according to other sources, to 438 000). Ninety percent of the deceased lived in African regions endangered by diseases, and more than 70% of victims were children under the age of five. On account of the global warming experienced in the past few decades, the danger that malaria may appear in areas not previously contaminated is quite realistic due to the increase in the habitat of the mosquitoes that spread the disease.

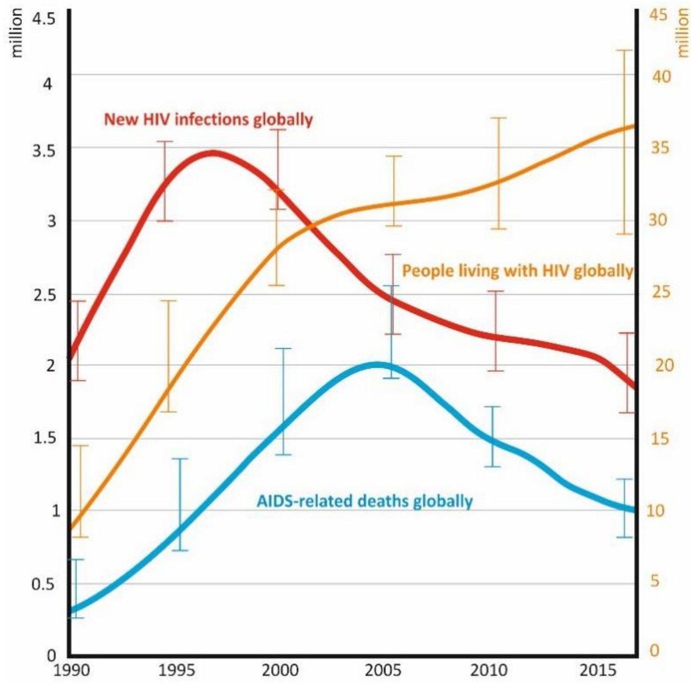

Fig. 4.16. AIDS infections and deaths between 1990–2015
(Source: data from UNAIDS, complemented using OurWorldinData).

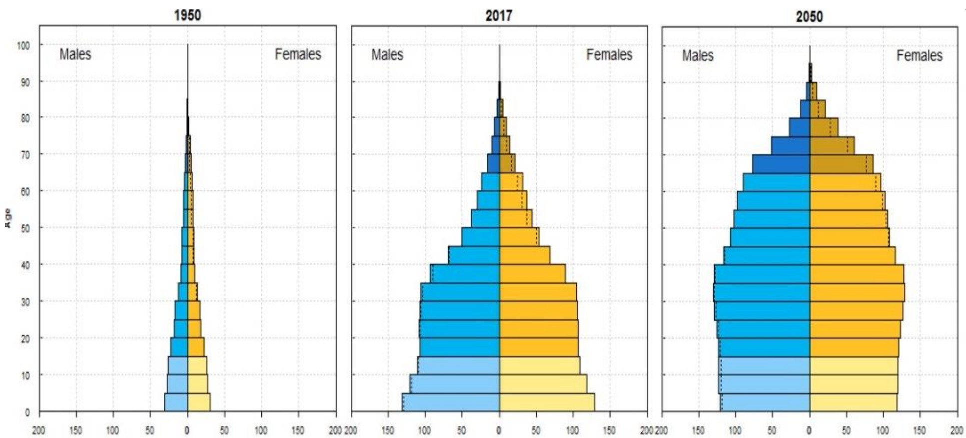

Fig. 4.17. The population pyramid of Botswana has significantly changed due to AIDS (Source: UNDP[32])

[32] You can find population pyramids and diagrams presenting the demographic relations of countries and regions at https://esa.un.org/unpd/wpp/Graphs/DemographicProfiles/ .

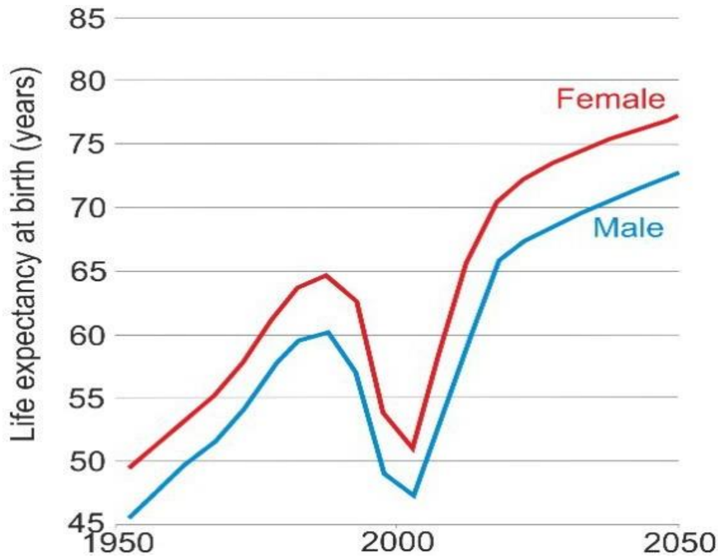

Fig. 4.18. Life expectancy at birth in Botswana (Source: UNDP)

4.6. International migration

Migration is as old as humanity as, according to present knowledge, Homo sapiens started off from Africa before populating the Earth. If you think about it, America was not discovered by Columbus as numerous people lived both in North and South America before his arrival. The descendants of the once-indigenous people now see this 'discovery' as the beginning of a process of genocide. To this end, for example, a statue of Columbus was demolished in Venezuela in 2004, and a statue of Pizzaro was also removed from one of the most central squares in Lima, the capital of Peru. The majority of the population of the USA today is also of immigrant origin.[33]

International migration is part of globalisation, accelerates as globalisation speeds up, and increases proportionately faster than global population growth (Fig. 4.19). Between 1970 and 2017, the number of migrants increased by more than three times, and their share in the population increased from 2.3% to 3.4%. Migration is encouraged by emerging economic-commercial relations, the new dimensions of transportation, the search for new living opportunities due to economic crises, the ever-wider opportunities provided by information flows, and wars, complemented by several other effects.

[33] By definition, a migrant is a person who lives in a country different than his/her home country.

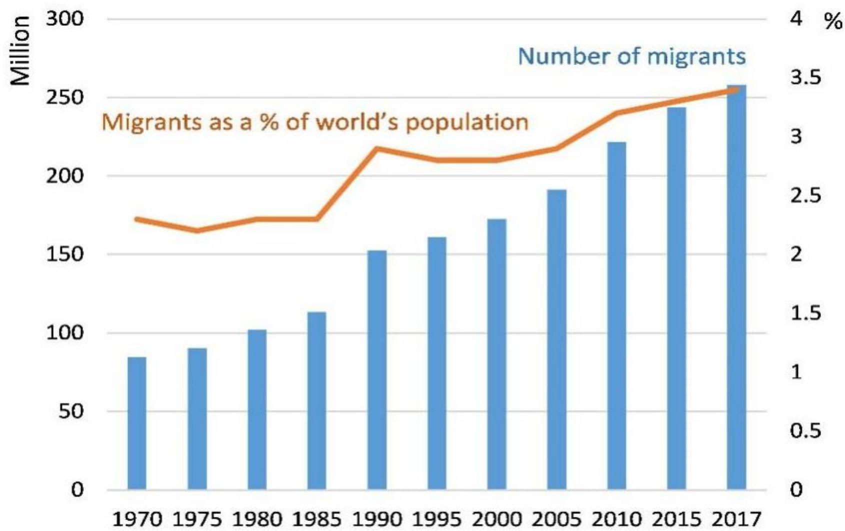

Fig. 4.19. Number and share of migrants compared to the world population between 1970–2017 (Source: IOM[34])

In trying to categorise the reasons for migration, we can identify 3+1 drivers, plus their combinations.

a) *Economic migration*. This is characterised by migration for better living conditions. The globalisation of information plays an important role in the acceleration of this kind of migration. Previously, people could only get information about the 'fantastic' opportunities of the 'new world' from relatives or friends returning home, news articles or other correspondence. Today, however, the TV and internet are accessible to almost everyone, showing a wide variety of the miracles of consumption and encouraging us to consume – which is often not locally possible.
b) *Refugees*. These individuals typically move to escape war, racial, religious or national discrimination for the purpose of reaching safety and often just to stay alive. This process is often not even voluntary: think about the expulsion of people by armed forces (the genocides of Rwanda, the Yugoslav Wars, the violent population changes following World War II, or the genocide of the Myanmar that still continues today).
c) *Environmental migrants*. Involving forced movement of the population by natural or environmental disasters. The volcanic explosion on the

[34] Detailed analyses about migration processes are available at: https://publications.iom.int/system/files/pdf/wmr_2018_en.pdf

island of Santorini in the Greek islands also destroyed the Minoan culture, and the tsunami triggered by the same process also belongs in this category. Such movements have also been caused by great droughts, desertification, plagues of locusts and epidemics, etc. Looking into the future, the problems of livelihood and water shortages due to climate change and, in the long term, the rise in the sea level may also force people to move. Mankind can also cause problems of this kind: infertility due to soil degradation (soil erosion, salinization), radioactive fallout following nuclear bombing or accidents, etc.

d) *Other*. Other than the three main causes mentioned above, there are numerous other reasons, sometimes only involving the movement of smaller groups of people. These include family relations (international marriages, family reunions), changes of country due to education, scientific, sports or military activities, often originally only planned to be short term. Political decisions that divide a people due to a change in borders or when people are divided by a new border from their mother nation may drive out larger masses of people.

In everyday language, the concepts of 'migrant' and 'refugee' are often used interchangeably. This, however, is confusing, as although all (international) refugees are migrants, not all migrants are refugees. The categorisation above does not involve strict boundaries – in real life the reasons for migration may overlap in several ways, and categorisation into particular groups is also more complicated. The definition of economic migration seems the simplest one, but the results of the Potato Famine in Ireland of the middle of the 1840s capture the complexity of the issue well. An environmental issue (a virus that infected potatoes) caused the most severe famine of the nineteenth century in Europe: one million people died, and two million people migrated in the following years. Those who left the country shortly after the disaster may be considered environmental migrants, while those who left later on can be considered economic migrants.

Today, international migration is often pictured as a phenomenon that poses a danger to the target country. However, the situation is much more complicated. Colonial countries were often targets of migration. This was the parent country's means of obtaining a cheap workforce that would perform low-skilled jobs. The black population of France and the United Kingdom is a result of these kinds of relationships, and members of this migrant population have been able to integrate into their new homes quite well until the last decade and are therefore proud to consider the target countries their new home (this phenomenon is clearly visible amongst athletes). The one-and-a-half million Turkish people in Germany have arrived due to temporary migration starting in the 1960s and today the majority of them have integrated into their new society successfully, despite differences in religion. The majority of the population of the USA is of foreign origin. Migration in the direction of the USA is continuous, and is an important quantitative and qualitative factor in population growth. For example, the USA accepted many outstanding scientists escaping from antisemitism before World War II and who have played a significant role in the success of the country. The 'Visa Lottery' that also functions today mirrors the more open approach of the country towards migration.

However, migration is also associated with many social risks. The majority of the people who settle in new host countries socio-economically belong to lower income categories, and generally obtain low-paying jobs (if they can or even want to work at all). Criminals may easily mingle amongst 'simple' migrants (e.g. previously the Italian Mafia in the USA, and the Russian, Ukrainian, Albanian, etc. Mafia in Europe since the 1990s), and so have terrorists in recent years. Although these groups are of smaller number, the otherwise quite heterogeneous mass of immigrants may be judged based on the host society's opinions of them. Physical barriers have also been established in many regions to prevent accelerated migration (and to prevent its harmful effects) due to failures with administrative restrictions. The border fence that has been built in Hungary is not unique in the world. India has built a fence on sections of the country that border Bangladesh and Pakistan that can be seen from space at night time (Fig. 4.20). (The contradictoriness of the situation is clear from the fact that a quarter of a century ago it was Hungary that played a dominant role in the reunification of Germany by eliminating the fence on the Hungarian-Austrian border that prevented immigration, thereby accelerating the transition to democracy of Eastern Europe.)

In 2017, two hundred and fifty-eight million international migrants were registered. Targeted areas of migration included the following: Asia (eighty million people), Europe (seventy-eight million) and North America (fifty-eight million). However, it is important to note that more than half of this migration took place within the boundaries of continents. In Asia, sixty-three million, in Europe forty-one million, and in Africa nineteen million people migrated within their own continents (Fig. 4.21).

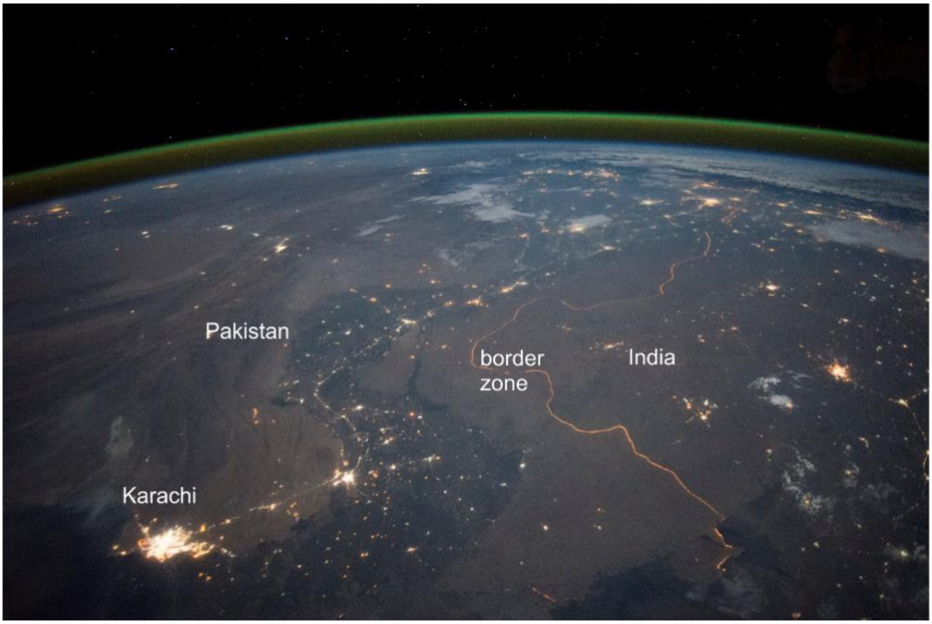

Fig. 4.20. The brightly lit border between India and Pakistan from a recording taken by the International Space Station (ISS) on September 23, 2015.[35]

Examining migration on a country level, the USA led amongst host countries (until 2017) (49.8 million people), followed by Saudi Arabia, Germany and Russia (approximately 12 million). The countries from which the largest number of individuals emigrate are typically the most populated ones: India (16.6 million), Mexico (13 million), Russia, China, and Bangladesh (Figure 4.22). They have recently been joined by Syria, due to the civil war (7 million). In many countries, the migrant population now represents a significant share of the total national population. This proportion amounts to 88.4% in the United Arab Emirates, 35% in Jordan, 32% in Saudi-Arabia, 29.4% in Switzerland, 28.2% in Australia, and 15% in the USA. However, there are huge differences amongst these countries. The economic migrants residing in the UAE who work on large-scale construction works are not permanent settlers; their numbers fluctuate periodically and will scale down significantly with the likely drop in construction. The USA, Switzerland and Australia are more appealing to immigrants. Jordan, the 'island of peace', is the nearest safe target of Middle-Eastern refugees (Palestinians, Syrians) who are escaping the circumstances of war.

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[35] The record is accessible at:
https://earthobservatory.nasa.gov/IOTD/view.php?id=86725

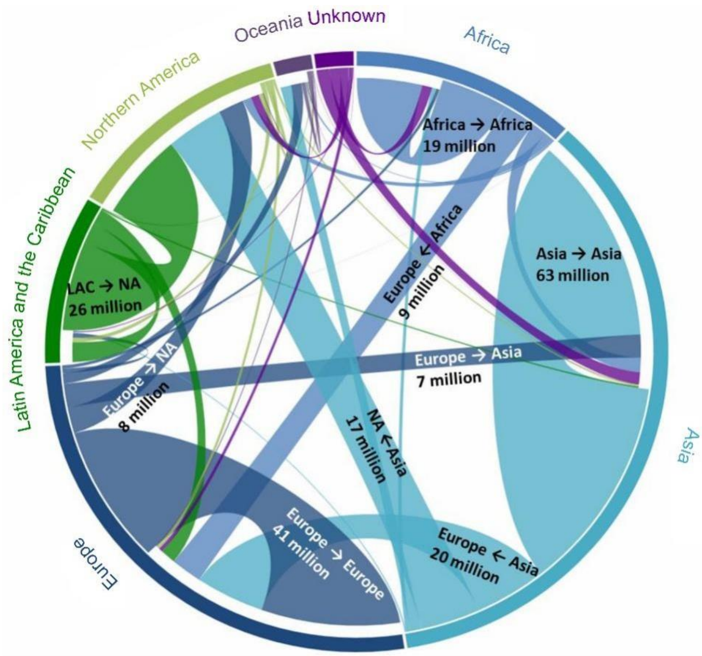

Fig. 4.21. Main directions of international migration (UN 2017)

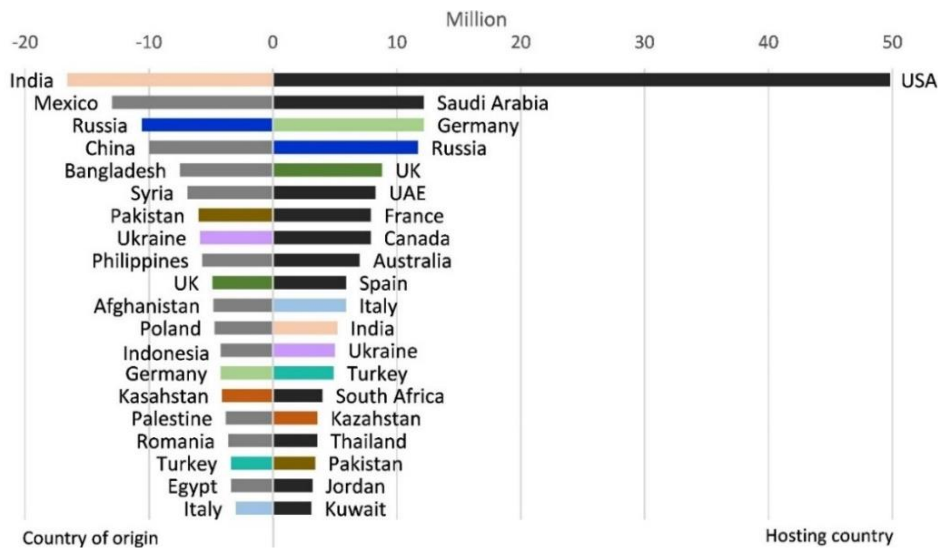

Fig. 4.22. The twenty largest target countries and countries of origin of international migration in 2017 (million people)

Well-defined country relations can be identified in the international migration process (Table 4.2). Looking at the twenty countries of origin with the most immigrants and the twenty most important host countries, we see that nine of them are listed in both groups and there are mutual cases. A unique situation was created by the disintegration of the Soviet Union, where population exchange took place/is taking place essentially between Russia and the countries which split off, from which Ukraine and Kazakhstan stand out in terms of numbers. This process, however, is only 'international migration' in a statistical sense, as the settlement of people with an identical mother tongue results in ethnically more unified countries.

Table 4.2. The most significant country relationships in terms of international migration in 2017 (million people)

Mexico	→ 12,7		USA
India	→ 3,3		UAE
Russia	→ 3,3	← 2,6	Ukraine
Syria	→ 3,3		Turkey
Russia	→ 2,4	← 2,6	Kazakhstan
Bangladesh	→ 3,1		India
China	→ 2,4		USA
China	→ 2,3		China (Hong Kong)
Afghanistan	→ 2,3		Iran
India	→ 2,3		USA
India	→ 2,3		Saudi Arabia
Philippines	→ 2,1		USA
Palestine	→ 2,0		Jordan

International migration has significant economic implications. This can be seen in a physical sense in, for example, the rapidly growing high-rise buildings of Dubai built by foreign workers, but also in the flow of money that is invisible to the eye. Economic migrants maintain close relationships with their mother countries (they often go abroad in the interest of their families). In 2016, bank remittances to developing countries amounted to approximately four hundred and thirteen billion dollars. This magnitude of this can be understood by knowing that if this were a country's GDP, the country would be ranked 25th in terms of global GDP country rankings. For some time now, bank remittances have had a negative effect on the economies of the USA and Saudi-Arabia, while the majority of the money that is remitted flows into India and China (Table 4.3) as a result of the migration processes that commenced earlier.

Table 4.3. Top countries for receiving/sending remittances (2000 and 2015) (current USD billions) (Source: WorldBank)

Countries sending remittances				Countries receiving remittances			
2000		2015		2000		2015	
USA	34,4	USA	61,38	India	12,84	India	68,90
Saudi Arabia	15,4	Saudi Arabia	38,79	France	8,61	China	63,94
Germany	9,04	Switzerland	24,38	Mexico	7,52	Philippines	28,48
Switzerland	7,59	China	20,42	Philippines	6,96	Mexico	26,23
France	3,77	Russia	19,70	South Korea	4,86	France	23,35
UAE	3,68	Germany	18,56	Spain	4,86	Nigeria	18,96
South Korea	3,65	Kuwait	15,20	Turkey	4,56	Pakistan	18,85
Israel	3,26	France	12,68	USA	4,40	Egypt	16,58
Japan	3,17	Qatar	12,19	Germany	3,64	Bangladesh	15,38
Netherlands	3,13	Luxembourg	11,35	UK	3,61	Germany	15,36

5. Global climate change and environmental atmospheric problems

Considering global environmental changes, the most obvious problems are connected with the atmosphere. This is because air is the most mobile transport medium, particles in it can spread quickly over large distances, and their spread is barely limited. While for example in the case of water the terrain basically determines the direction of flow, the atmosphere may transport pollutants in any direction and far from their source, owing to their size.[36] An important consequence of this is that the effects of air pollution are not necessarily endured by the polluter. Another consequence concerns long-range pollutants, which can effectively become distributed in the atmosphere and may transform

[36]Pollutants can be classified into three groups based on their size and physical form: dust and soot (>10 μm, solid), aerosols (10–0.01 μm, solids [e.g. fine dust], fluids [e.g. fog] and their mixtures too [e.g. fumes], gas and vapour. Heavier pollutants are deposited sooner, thus they travel shorter distances.

the local and regional effects of pollution into global problems. It is well known that the dispersal of radioactive particles released into the atmosphere by nuclear explosions is of a global character, and these particles can be detected worldwide. For example, the effects of the Chernobyl disaster were observed across the whole of the northern hemisphere within a few weeks.

Different types of pollution may generate diverse effects in the atmosphere. The most serious environmental problem is currently global climate change (especially global warming), which is caused by the large increase in (anthropogenic) greenhouse gas emissions. The effect of climate change can be observed globally, and numerous consequences (e.g. a reduction in ice sheets, desertification, and changes in El Niño) are obvious across large areas. The effects of climate change have become increasingly recognizable since the late 1980s. Before then, two important global atmospheric problems were dominant: acid rain, from the middle of the 1970s, and the ozone depletion problem in the 1980s (the ozone hole was discovered in 1985). Although acid rain is a more of a regional problem, because of its continental-scale effects it may be regarded as a global issue.

5.1. The composition and temporal changes in the atmosphere

The present composition of dry air (nitrogen: 78.08%, oxygen: 20.95%, argon: 0.93%, carbon dioxide: 0.04% by volume) has evolved through long-term change over geological time. The atmosphere of the early Earth was mainly composed of hydrogen and helium. Later, when the lightweight gasses escaped from the atmosphere, the proportion of methane, nitrogen, water vapour and carbon dioxide increased, but the proportion of oxygen remained low for a long time. In the evolution of the present atmosphere, photodissociation (the separation of water vapour into molecular hydrogen (H_2) and molecular oxygen due to the energy of light) was an important process which induced the formation of ozone (O_3) due to the UV radiation of the Sun. Ozone in the upper atmosphere (that absorbs ultraviolet light) allowed early life forms to begin to safely move from the oceans onto land. Approximately nine hundred million years ago, the oxygen content of the atmosphere reached one-thousandth of the present value (called the Urey level[37]); the level sufficient for a sufficiently effective UV-absorbing effect. The propagation of photosynthetic life forms sped up oxygen formation, thus about six hundred million years ago the oxygen content of the atmosphere reached one-hundredth of the present value (the Pasteur level), allowing the evolution of respiratory metabolisms and accelerating further the evolution and propagation of life and also changes in atmospheric composition. As a result of

[37]After H.C. Urey, an American researcher who focused on this topic.

this process, an oxygen level similar to that of the present evolved approximately three hundred million years ago. The role of living organisms was not limited to affecting the level of oxygen; the respiration of vegetation exploited the carbon-dioxide content of the atmosphere. The metabolism of vegetation removed considerable amounts of CO_2 from the atmosphere, mainly locking it up in coal deposits and carbonate rocks (limestone and dolomite). This process was not continuous; it was interrupted for shorter periods by the reverse form of change, although this was mainly due to natural processes. Human activity on Earth has changed this natural balance fundamentally, not just by modifying the cycle of natural resources, but by introducing foreign substances into the atmosphere.

5.2. The background to global climate change

5.2.1. The greenhouse effect

The atmosphere of the Earth functions as an energy trap, similar to a greenhouse. In seeking a physical explanation of this phenomenon, the fundamental mechanism of the greenhouse effect should be explained.

Atmospheric gasses do not transmit all solar radiation: some radiation is partially reflected, some partially absorbed, and the remaining part is transmitted depending on the wavelength. Much short-wave radiation (e.g. X-rays and ultraviolet light) is absorbed in the stratosphere, although visible light, a significant part of solar radiation, is transmitted through the atmosphere almost unimpeded (Fig. 5.1). The radiation that reaches the Earth's surface – and interacts with surface materials – is transformed and re-radiated as longer wavelength thermal radiation (this can be felt on our skin) which can pass back out through the atmosphere with much less efficiency. The resulting heat surplus creates favourable conditions for life on our planet. Based on estimations, the temperature would be lower by 33 °C without this heat surplus, meaning a global mean temperature[38] on Earth of –18 ˚C. *The greenhouse effect, therefore, is favourable to life on Earth, but its strength is of great importance.*

Over the last millions of years, a very fragile balance has evolved in terms of the volume and proportions of atmospheric gasses on our planet, ensuring that Earth's average temperature has changed over a relatively narrow range.

However, human activities in the past 200-250 years have modified the composition of the atmosphere and the volume of most important greenhouse

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[38] A high gas content results in a constant temperature of around 480 ºC on Venus, while the very rare atmosphere on Mars does not allow the greenhouse effect to function properly, so by now it is permanently cold.

gasses at an increasing rate (Table 5.1). The relevance of the greenhouse effect and the results of human activity on our lives was realized only a few decades ago. One of the main reasons for this was that the aerosols emitted into the atmosphere and the resulting greater cloud formation reduced irradiation.

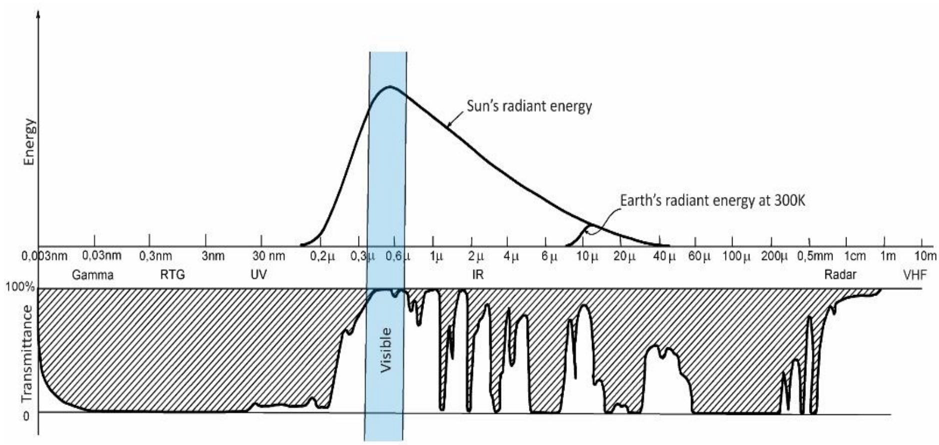

Fig. 5.1 Atmospheric transmission of electromagnetic radiation as a function of wavelength

Table 5.1. Proportions of and anthropogenic changes in the main greenhouse gasses (without water vapour) (Source WMO 2010)

Greenhouse gas	CO_2	CH_4	N_2O	CFC-11	CFC-12	HCFC-22	HFC-134a
	ppm	ppb	ppb	ppt	ppt	ppt	ppt
Concentration before industrialization	278	700	275	0	0	0	0
Present concentration (2018)	410	1860	330	228	510	240	102
Global warming potential (GWP)[39] (CO_2=1)	1	28	265	3800	8100	1760	4800
Atmospheric residence time (years)	5-200	9.1	131	45	100	12	13.4

[39] The warming potential of specific greenhouse-gas molecules is generally compared to that of carbon dioxide (Values depend on the timespan that is investigated).

Extensive industrialization after World War II induced not only a sudden increase in greenhouse gas emissions but also a high level of aerosol pollution, as a result of which processes the increase in the greenhouse effect remained barely noticeable. Thus, the warming of the atmosphere only became recognizable about two decades later (Fig. 5.2). Moreover, land-use changes and the resulting higher level of solar radiation reflection – so-called albedo changes – also mitigated the warming of the atmosphere.

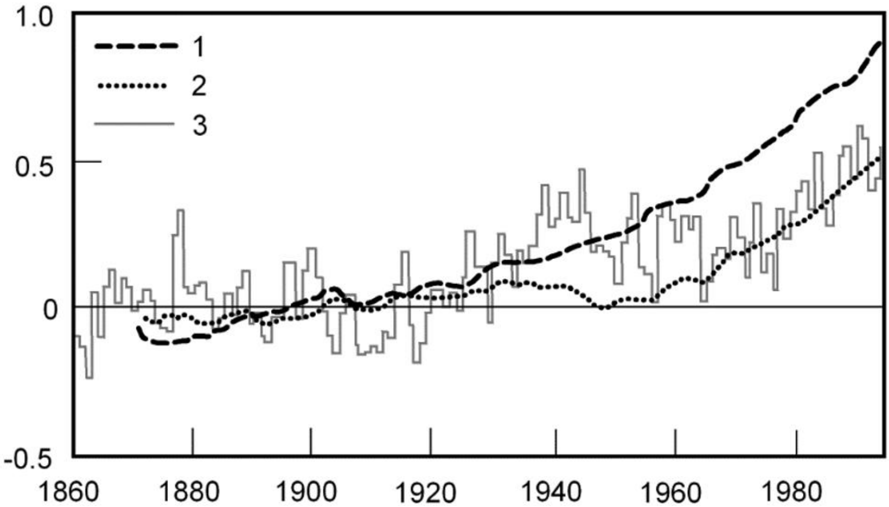

Fig. 5.2. Global annual mean warming from 1860 to 1990 (1: based on equivalent CO_2 only; 2: equivalent CO_2 and the direct effect of sulphur aerosols; 3: observed) (Source: IPCC)

Identification of the relative importance of greenhouse gasses shows that the most important one is water vapour! However, as the approximately thirteen trillion tonnes of water vapour in the atmosphere is scarcely dependent on human activity, its impact has been less investigated. However, human alteration of the Earth's surface and vegetation, irrigation, reduction of ice-covered surfaces, etc. may change the currently insignificant influence of humans on water vapour. First, only carbon dioxide was considered as a greenhouse gas, but now other low-concentration gasses that absorb in the range of 8–12 μm wavelengths have been recognized as being involved in the process. It is a historically interesting fact that Fourier (the renowned mathematician) mentioned the importance of CO_2 as early as in 1824, and it was then highlighted again at the end of the nineteenth century Arrhenius calculated that a doubling of atmospheric CO_2 would result in a temperature rise of 4-6 ˚C. The comprehensive monitoring of the atmospheric CO_2 level started in 1957/58 in the frame of the International Geophysical Year, initiated by Revelle. Technological development allowed the analysis of atmospheric paleo-CO_2 concentrations in the 1990s based on Antarctic and Greenland ice-core records. The long time records indicate that significant fluctuations also occurred in the past, but within a definite range (between 180 and 295 ppm[40] over the last four hundred thousand years) and were strongly correlated to climate change. The CO_2 concentration was only 280 ppm even in the nineteenth century, while at the time of the new millennium it had exceeded 370 ppm and in 2018 reached 410 ppm, thus today's CO_2 concentration has increased by a half, mainly over the last sixty years (Fig. 5.3). It should attract serious attention that these ever-increasing values are already far beyond those caused by the natural changes of the past.

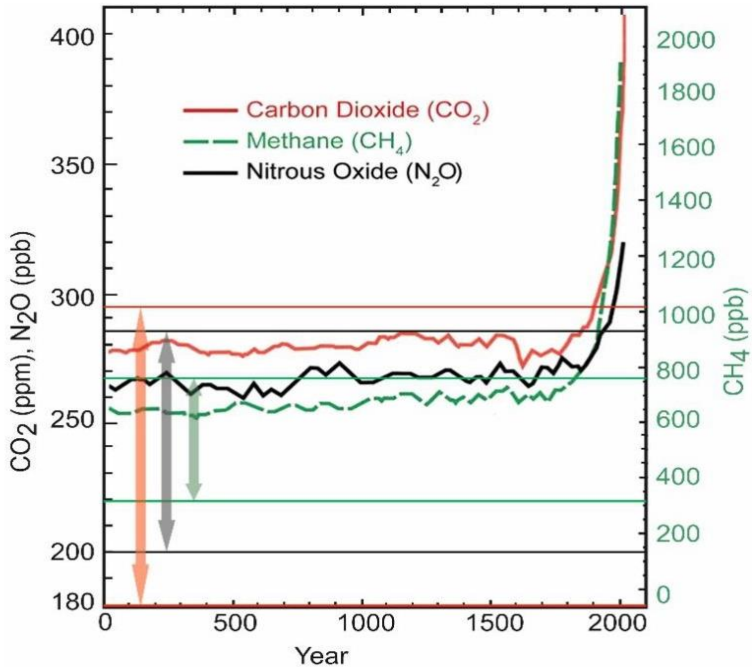

Fig. 5.3. Changes in concentration of the most important greenhouse gasses in the last two thousand years. The range of changes of the last four hundred thousand years is also indicated (Source of data: IPCC and NOAA/ESRL)

Examining the origin of the changes in CO_2 concentration, we see that the natural sources of this change arise from the respiration and decomposition of organic materials, while anthropogenic sources include fossil fuel combustion, biomass burning, and decreased CO_2 sequestration due to deforestation or the use of carbonate rocks. Detailed records from the last thirty years clearly show the trend in the CO_2 concentration and also the effects on the biosphere of

[40] ppm: parts per million (10^{-6}), ppb: 10^{-9}, ppt: $^{-12}$

seasons. Seasonal fluctuations can be seen in Fig. 5.4, caused by the significantly different extent of the continents (thus the volume of vegetation) in the northern and southern hemispheres. [41]

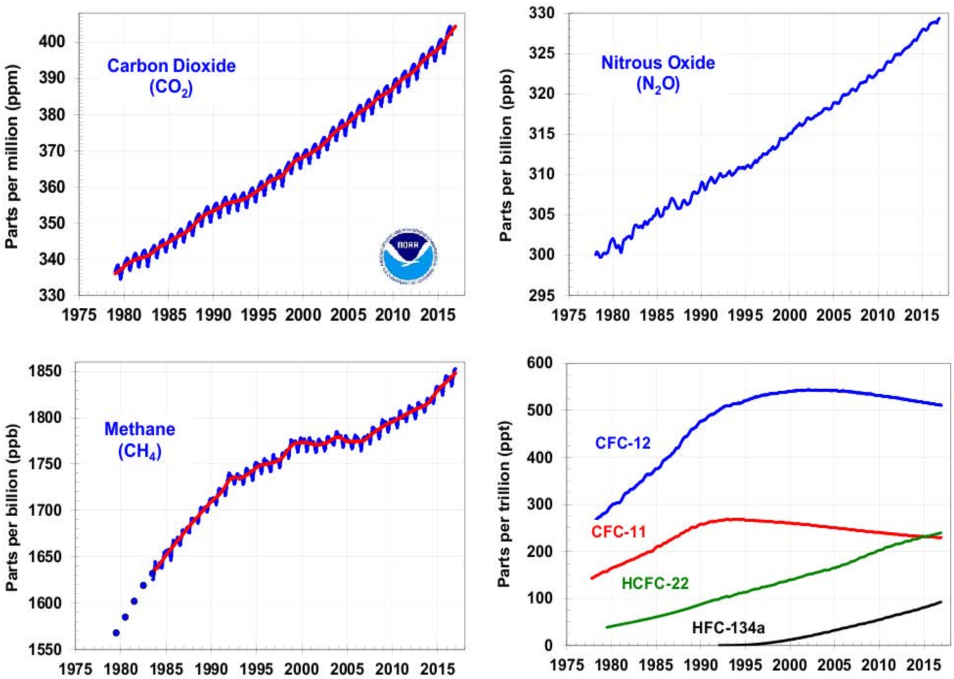

Fig. 5.4. Changes in concentration of the most important greenhouse gasses (1975–2015) (Source: *NOAA/ESRL)*

In the case of *methane* (CH_4), the human-induced increase in concentration has been even higher than that of CO_2: its concentration has doubled in the last two hundred years. Though its concentration is lower, it is an important greenhouse gas because of its Global Warming Potential (GWP): the warming potential of one CH_4 molecule is twenty-eight times more and ninety-five times higher per unit weight than the 'main enemy', CO_2. The longer-term changes in CH_4 are similar to those of CO_2 and its concentration is now also outside the range of natural changes. Its rate of growth slowed down in the 1990s, but since 2007 it has also started to increase at a faster rate (Fig. 5.4). Its concentration reached 1959 ppb in 2018. Besides the trend to a long-term increase, it fluctuates in a similar way to CO_2. The natural

[41] CO_2 changes can be illustrated using several animations. One of these shows changes from 800 thousand years until the present, representing latitudinal differences: in the Southern Hemisphere the changes are continuous, while in the Northern Hemisphere seasonal differences can be observed. Available online at:
http://www.esrl.noaa.gov/gmd/ccgg/trends/history.html

sources of CH_4 are decomposition and fermentation, while anthropogenic sources include rice production, mining, and industry. It is interesting to note that Australian scientists, recognizing the problem of greenhouse gasses, have developed a serum to reduce the intestinal gas of the cattle and sheep that 'produce' sixty million tonnes of CO_2-equivalent methane. The significance of CH_4 may considerably increase in the future due to the melting of arctic soils, or through release of methane hydrates from oceans due to global warming.[42]

The importance of *Nitrogen oxides* (especially N_2O) in the greenhouse effect may also increase. Anthropogenic sources include transportation, fossil fuel combustion, biomass burning, and the most important source, nitrogen fertilizers.

CFCs (also known as Freons) (freon 11: $CFCl_3$, freon 12: CF_2Cl_2) may also pose a significant risk in terms of increasing the intensity of the greenhouse effect because of their long residence time in the atmosphere and their significant global warming potential (Table 5.1). The use of the 'carriers' of these gasses, being inflammable and non-toxic to human beings, peaked between the 1950s and 1980s as ideal gasses for use as refrigerants in refrigerators. Later, their significance as greenhouse gasses was recognised, and also their role as the leading cause of ozone-layer depletion. Recently, their emission has been restricted by international conventions (see Chapter 16.2.1) and global emissions have decreased significantly, although their negative atmospheric effects can occur for decades.

Ice core records, as mentioned in the case of CO_2, provide a good opportunity to analyse the long-term changes in the above-mentioned gasses, except for the CFCs.

Further greenhouse gasses – although their role is insignificant compared to the previously discussed gasses – include sulphur hexafluoride, near-surface (tropospheric) ozone, and carbon monoxide. Their emissions are mainly connected to industry and transportation.

5.2.2. Past climate change on Earth

Paleoclimate research involves the use of several methodologies. For the last one-and-a-half centuries, relatively accurate observation-based data are available (although only for parts of the planet), while for the last 1-2 thousand years written historical records can provide information, and the study of ice-core records from Antarctica and Greenland can reveal paleoclimate information dating back eight hundred thousand years. On a geological time-scale, geological and palaeontological methods can be applied. Of course, the precision and temporal resolution of information significantly decreases as we

[42] The estimated total amount of 6.5 trillion tonnes represents a significant risk; however, the risk of its release is debated by scientists.

move back in time. By combining these methodologies, paleoclimatic changes can be understood for hundreds of millions of years. Numerous pieces of research have proved that the *Earth's history involves a series of climate changes*. Although in the life of individuals spectacular change cannot be detected, it is already known that in Earth's history there have been much warmer and colder periods (Fig. 5.5). We can surely conclude that the last ten thousand years (the Holocene) provided a relatively even and comfortable climate and was thus a fortunate time for mankind to live. Somewhat colder periods occurred even within this time-frame (e.g. the Little Ice Age), but living conditions were only slightly limited. However, during the Ice Age prehistoric man had to struggle to survive in much worse circumstances.

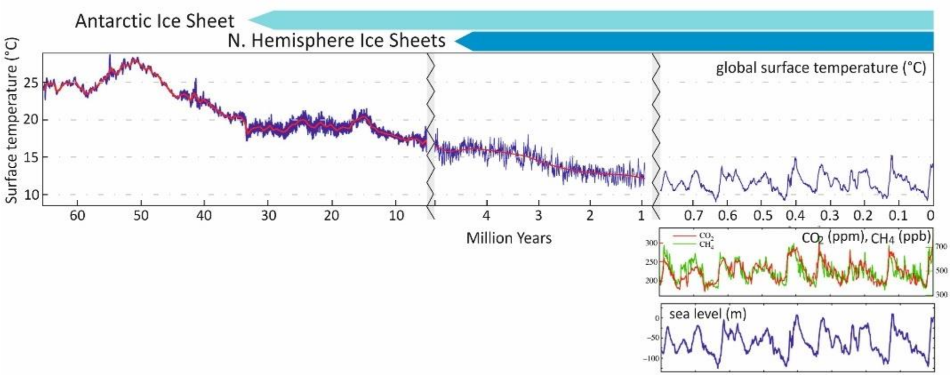

Fig. 5.5. Global mean temperature changes over the last sixty-five million years, and greenhouse gas and global mean sea-level changes in the last four hundred thousand years[43]

In earlier periods of Earth's history before the Tertiary (sixty-five million years ago) the climate was normally much warmer, although geological records indicate at least six ice ages occurred just in this period. The Eocene temperature maximum (fifty-five million years ago) was 12 °C higher than the present global temperature mean (15 °C).

With the gradually decreasing temperature, the Antarctic ice sheet began to develop thirty-four million years ago, and the glaciation of the Arctic started 4.5 million years ago. From the beginning of the Pleistocene – owing to the further cooling of the climate – a series of glaciation can be studied in detail. Glacial stages were interrupted by interglacials. The overall amplitude of the glacial-interglacial temperature change reached as much as 6-10 °C, and this temperature variation was especially extreme in the one hundred thousand

[43] The illustration was made using figures from http://www.globalwarming-sowhat.com/ and the Antarctic Ice Core findings.

years immediately preceding the Holocene. Based on the Antarctic 'Vostok' ice-core records, the maximum rate of rapid temperature increase was 0.05-0.1 °C/100 years. Accordingly, the temperature increase over the last one hundred years (exceeding 1 °C) compared to that found in the ice-core records is cause for concern. Significant temperature changes resulted in significant sea-level change: during the glacial maximums sea level was about one hundred meters lower than it is today (Fig. 5.5).

Based on long-term climate records it can be concluded that much warmer and colder periods occurred in Earth's history before human influence was felt on the environmental system. With the present climate change, not only is the degree of change concerning, but especially its speed. About 252 million years ago, because of a rapid warming process, around ninety-five percent of marine life and seventy percent of life on land was wiped out during the '*The Great Dying'*.

5.2.3. The process, background and major consequences of current climate change

The economic growth that followed the Second World War had major environmental impacts, and still has today. The consequences were recognised on the regional level in the first 1-2 decades (e.g. urban smog, rivers have become wastewaters, expanding landscape scars, or deforestation), and the processes have become global issues that are especially relevant and complex in the atmosphere owing to the potential for rapid (pollutant) transport. The consequences of CO_2 emissions reached a critical level in the 1980s when their climate-modifying effect was recognised. The importance of this phenomenon was often denied or underestimated initially, especially by the larger emitters. It was an important step forward when the *World Meteorological Organization* (WMO) and the *United Nations Environment Programme* (UNEP) established *The Intergovernmental Panel on Climate Change* (IPCC), which was designed to assess the results of research into human-induced climate change. The IPCC does not carry out its own research but summarizes the scientific evidence found by scientists around the world. The organization had to overcome many difficulties, but the quality and the present international acceptance of its work is clearly demonstrated by the Nobel Peace Prize it was awarded in 2007 (shared with former US Vice President, Al Gore). The results of their scientific and technical assessments have regularly been published in Assessment reports since 1990.[44] The assessments clearly

[44] Reports are available at: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

indicate that the significant increase in greenhouses gasses is playing an important role in the present global climate change. To assist the international scientific community in establishing a common, mutually agreed on knowledge base for supporting policy debate and action to slow the rate of increase of greenhouse gasses in the atmosphere, the Global Carbon Project was formed through international scientific cooperation in 2001.[45]

Greenhouse gasses

The human effect on the concentration of greenhouse gasses can be seen in Table 5.1. Besides natural greenhouse gasses, several artificial gasses have been introduced into the atmosphere in the last century which were later identified as important contributors to the greenhouse effect or the formation of the ozone hole. When the negative environmental effects of CFCs (for example) were revealed, their application was reduced or replaced with alternative HCFCs and HFCs. These alternatives, such as HCFC-22 and HFC-134a (see Table 5.1), do not deplete the ozone layer, although they have also been identified as potent greenhouse gasses, and are also very active in terms of the climate. Global emissions of HFCs are significantly increasing (because of their widespread application) and in the northern hemisphere, where most industrial production is concentrated, their concentration has increased by 10-15 ppm in the last 15 years.[46]

The importance of greenhouse gasses in global warming (Fig. 5.6) and their rates of emission are different because of their very diverse lifetimes in the atmosphere. Thus, while the significance of CFCs in present emissions is negligible (thanks to international environmental agreements), their impact on global warming has not changed for a long time, though their relative importance has slightly decreased lately (Fig. 5.6 and Table 5.2). This shows the importance of the speed of intervention, as was emphasized by the Meadows models. Delaying intervention in an unfavourable process may not lead to the expected results. Table 5.1 also shows that the importance of other artificial gasses is continuously increasing, and has doubled since 1980.

[45] The project focuses on the two most important greenhouse gasses (CO_2 and CH_4): http://www.globalcarbonproject.org/carbonbudget/index.htm
[46] See: https://www.esrl.noaa.gov/gmd/hats/gasses/HFC134a.html

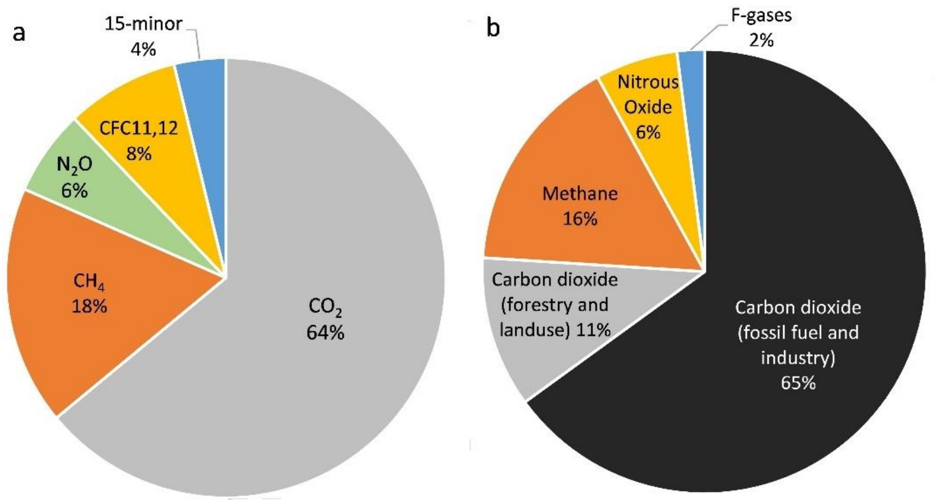

Fig 5.6. The relative importance of greenhouse gasses (CO_2 equivalent) in terms of emissions (b) and global warming (a) in 2010 (data source: IPCC and NOAA/ESRL)

Table 5.2. Global Radiative Forcing of greenhouse gasses from 1980 to 2016[47] (%)

Greenhouse gasses	CO_2	CH_4	N_2O	CFC11,12	15-minor
1980	60.6	23.6	6.0	8.0	1.8
1990	59.7	21.2	6.0	10.1	3.0
2000	61.3	19.5	6.1	9.7	3.4
2010	64.0	17.6	6.3	8.3	3.8
2016	65.6	16.6	6.5	7.3	4.0

In the present atmosphere, the proportion of greenhouse gasses – except for water vapour – is only slightly more than one four-hundred-millionth part of the total atmosphere (410 ppm in 2018): however, this amount is enough to significantly endanger the ten-thousand-year stability of the global climate. The most important gas is CO_2 (Fig. 5.6), responsible for 76% of total greenhouse gas emissions (65% from fossil fuels and industry, 11% from land use). The volume of CO_2 has increased by half in the last quarter-century (1990: 22 Gt, 2016: 36.2Gt).[48] This huge amount of CO_2 has fundamentally changed the composition of the

[47] The calculation is based on https://www.esrl.noaa.gov/gmd/ccgg/aggi.html
[48] An animation illustrating the spatial and temporal changes of CO_2 from 2002 to 2016 can be seen at https://climate.nasa.gov/interactives/climate-time-machine

atmosphere that evolved over the last one-thousand years. In the period 2007–2016, only approximately half of the CO_2 that was emitted could be absorbed by natural processes, while the other part (17.3 Gt) remained in the atmosphere, contributing to its warming (Fig. 5.7).

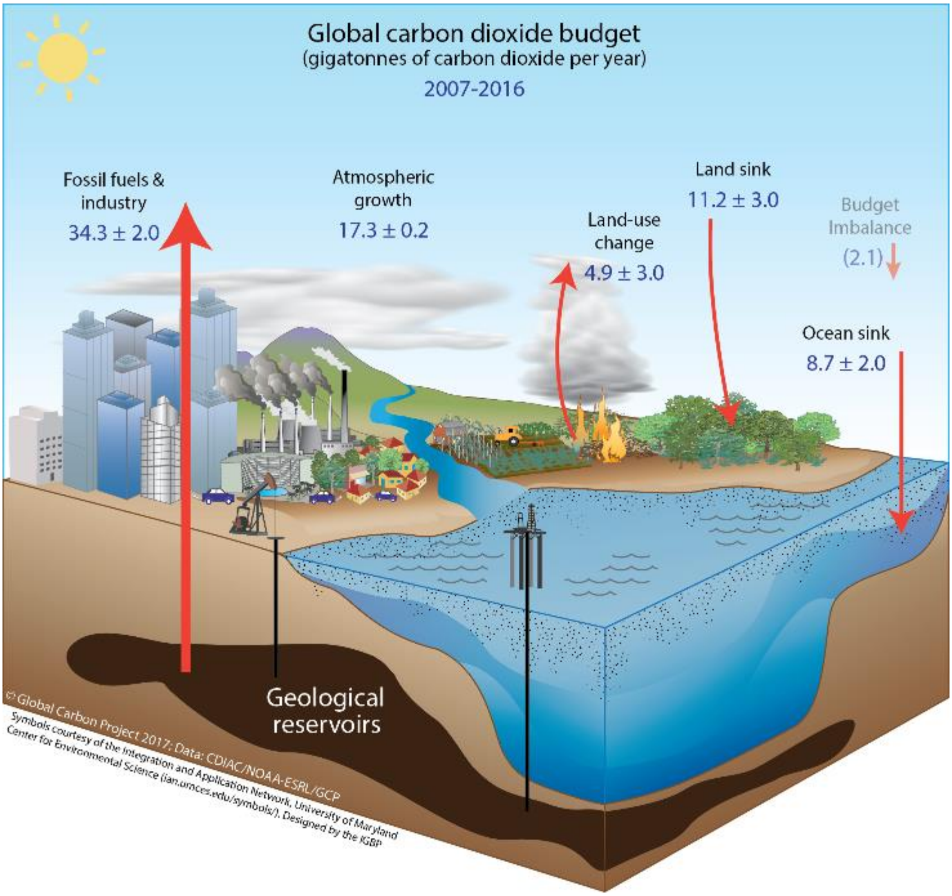

Fig. 5.7. Global carbon dioxide budget 2007–2016 (Gt/year)
(Source: Global Carbon Project)

Global warming and its consequences

The excess heat retained by the atmosphere leads to the warming up of land surfaces and global seas. This process can be identified by changes in mean surface temperatures Fig. 5.8 and 5.9) that show a 1 °C increase globally during the last 150 years, while the rate of increase was higher on land surfaces. The temperature change was not uniform across the Earth: on large parts of the planet it exceeded 1.5 °C, but only a small area was affected by a slight temperature decrease.

The temperature increase can be clearly detected in environmental changes, and most spectacularly by the extent of ice-covered surfaces. These changes in ice-covered surfaces follow changes in atmospheric temperature after a delay and data smoothing. The effect of temperature extremities is not directly observable, but the trend of the changes is clearly visible. Thus, changes in the extent of ice-covered surfaces is an excellent indicator of climate change. Evidence indicates that the melting of ice-covered surfaces may cause significant environmental risk, even in the near future.

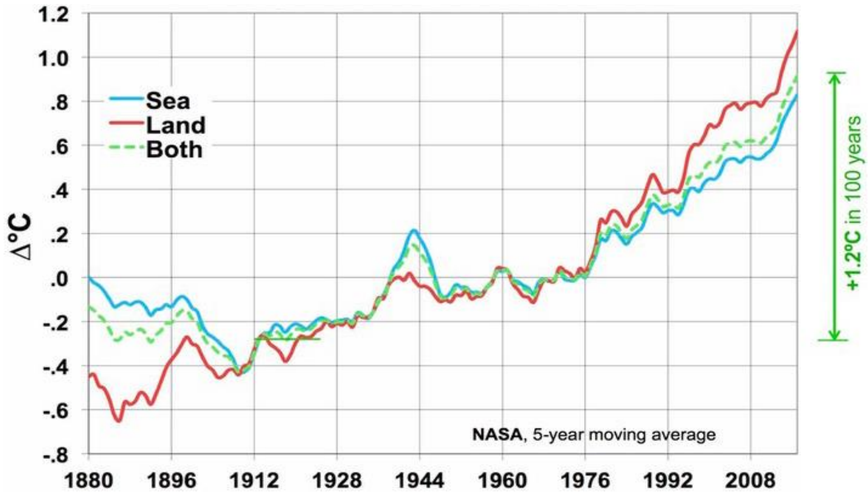

Fig. 5.8. Global mean temperature change of land surface and seas from 1880 to 2017 (five-year moving average) (Source: NASA)[49]

Arctic sea ice has noticeably decreased, particularly over the last decade. Yearly maximum ice cover varied between 15.7 and 16.3 million km^2 in the 1980s, but in the last decade (2009–2018) it decreased to between 14.4 and 15.3 million km^2. The sea ice minimums in summer have experienced even greater change. Typical sea ice minimum cover (7-8 million km^2) has decreased significantly over the last decades and reached a dramatically low amount in 2012 (less than 3.4 million km^2 in the middle of September) (Fig. 5.10).[50]

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[49] Source: http://www.globalwarming-sowhat.com/warm--cool-/ ,
a https://climate.nasa.gov/vital-signs/global-temperature/ (continuously updated). The figure also shows combined land and sea data (a global land-ocean temperature index). An animation illustrating the spatial temperature differences since 1884 can be seen at https://climate.nasa.gov/interactives/climate-time-machine .

[50] Up-to-date data can be obtained at http://nsidc.org/arcticseaicenews/ and on an interactive map the data for selected years can be seen:
https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/

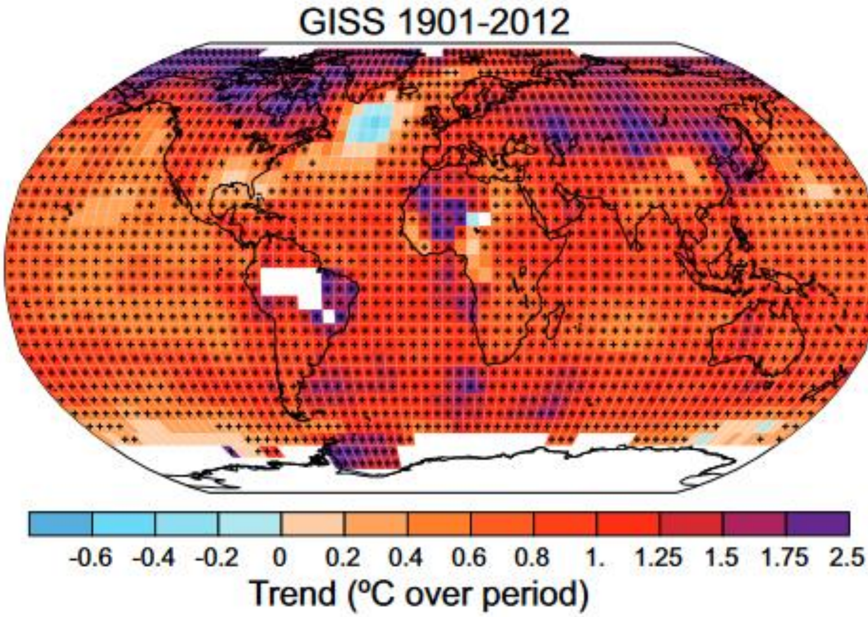

Fig. 5.9. Mean temperate change in the period 1901–2012 (Source: IPCC)

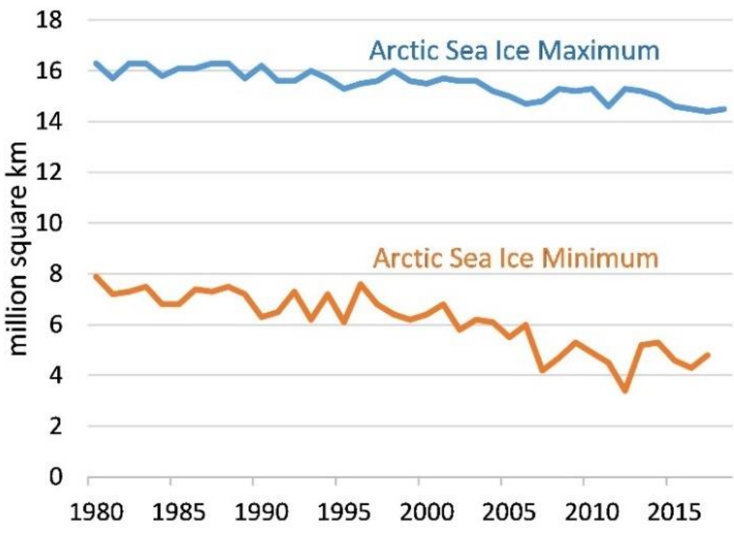

Fig. 5.10. Maximum and minimum extent of Arctic sea ice cover (km^2) from 1980 to 2018 (Data source: NSIDC and NASA)

An important consequence of ice-cover changes has been that the year-by-year decline in the extent of Arctic sea ice now allows commercial traffic to pass through the Northwest Passage. The thickness of the sea ice has also declined – its thickness in around 2000 was estimated to be only 40% of the average of the 1950s (measurements by military submarines indicated a decrease in ice thickness previously, but these data were withheld for strategic reasons). The accelerated rate of melting is indicated by the changes in the Greenland ice sheet. The yearly average decrease in ice mass was 34 Gt in the period 1992–2001, but this increased by six-and-a-half times in the following decade (2002–2011) to 215 Gt/year. Considering the trends, estimates assume that Arctic sea ice will totally disappear by 2040 (or even earlier). This has already sparked efforts by the world's most powerful economies to claim the hydrocarbon resources under the Arctic.

Such noticeable changes have not been observed in the ice cover at the Antarctic: the melting of ice cover was larger than average in 2017, but less than average in 2014. However, the general trend is towards an accelerating melting process: the yearly average decrease in ice mass was 30 Gt in the period 1992–2001, but had increased to 120-200 Gt/year by the period 2013–2018, which is nearly the half of the melting rate in Greenland.

There are huge changes with glaciers too. On the internet, countless pairs of photos show the retreat of glaciers. Overall, around 85% of our planet's glaciers are declining water resources, amounting to losses of 259 Gt annually (the average of the 2003–2009 period). Alaska (50 Gt), the Arctic part of Canada (60 Gt), Greenland (38 Gt), the Mountains of the South Andes (29 Gt) and high mountains in Asia (26 Gt) are all affected by the decline. The reduction in the water stored in glaciers poses a significant problem, particularly in areas where they supply a significant part of the population's water. A lack of freshwater due to vanishing glaciers resulted in riots in La Paz (Bolivia) in 2017.

On the tundra, the melting of frozen soil contributes to spectacular environmental problems. Melting ice causes serious damage to infrastructure,[51] and methane released from soil (estimated at up to five hundred million tonnes per year, close to double that of methane emissions) may significantly increase the greenhouse effect. The warming up of the tundra also causes difficulties for road transport. In the absence of unpaved roads, transport vehicles can only move around when a thick layer of soil is frozen. In the 1960s, the frozen period lasted two hundred days a year, but it had decreased to half of this by the beginning of the 2000s[52] (in the past few years in Alaska the situation has been somewhat more favourable for transporters). The rapid changes in the Arctic and tundra are due to higher-than-global temperatures (Fig. 5.11).

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[51] A search for ‘permafrost melting’ or ‘permafrost melting effects’ on the internet will turn up many illustrative images.

[52] This problem was also emphasised by Al Gore, former US vice-president, in a book entitled *An Inconvenient Truth*.

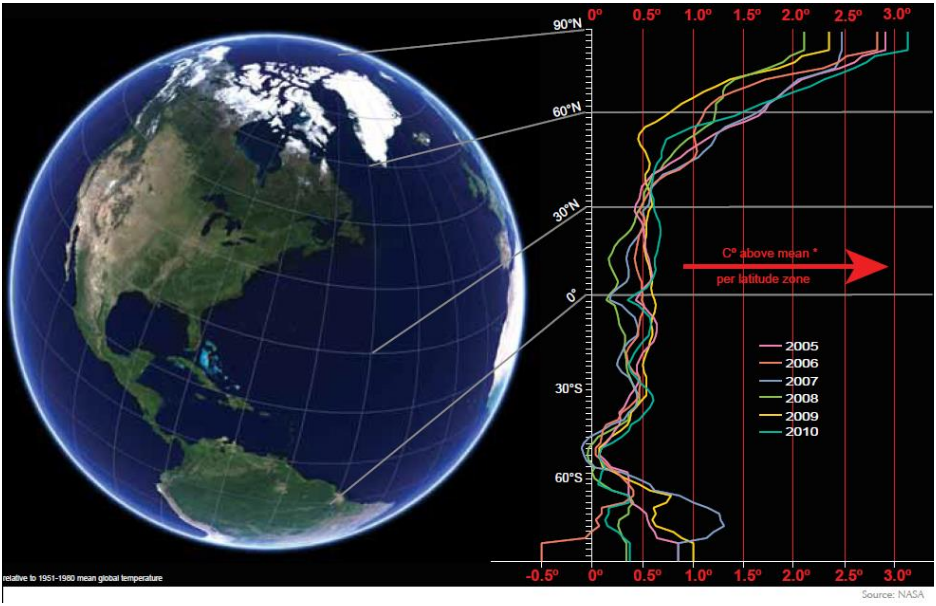

Fig. 5.11. Latitudinal Temperature Changes (relative to 1951–1980 mean global temperature) (Source: UNEP 2011)

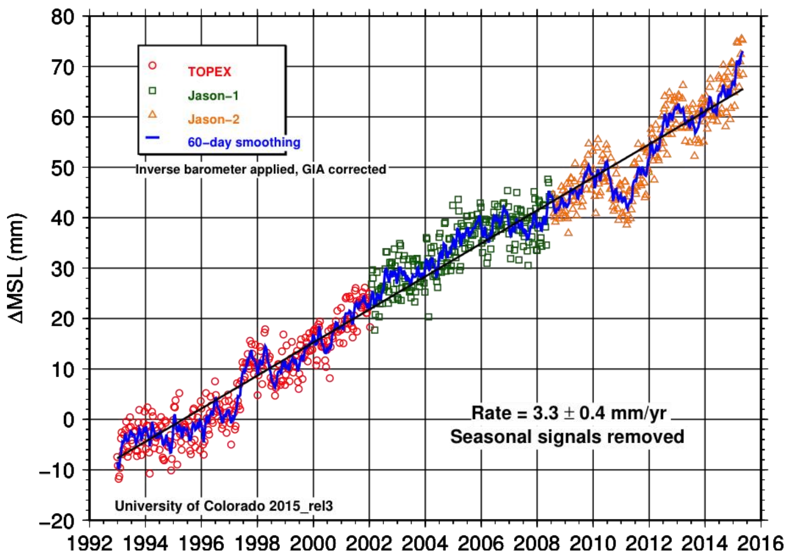

Fig. 5.12. Global-mean sea level from satellite altimetry[53]

[53] Nerem, R.S. & National Center for Atmospheric Research Staff (Eds). Last modified 19 Jan, 2016. *The Climate Data Guide: Global Mean Sea Level from TOPEX & Jason Altimetry*. Retrieved from https://climatedataguide.ucar.edu/climate-data/global-mean-sea-level-topex-jason-altimetry .

Ice melting on land causes the sea level to rise.[54] The sea level has increased by 20 cm over the past hundred years, of which the decline was 6 cm over the last 20 years, thus the current rate of change is 3 mm/year (Fig. 5.12). However, it should be noted that half of the increase is due to thermal expansion, and 'only' the other half is caused by melting. This change represents a threat to humanity because 40% of the Earth's population live near the coast, thus a 20-cm change would endanger approximately fifty million people. A rise in sea level of one meter would result in more than two million km^2 being flooded and the forced migration of 145 million people (mainly in Asia), and would also cause significant economic damage (Fig. 5.13).

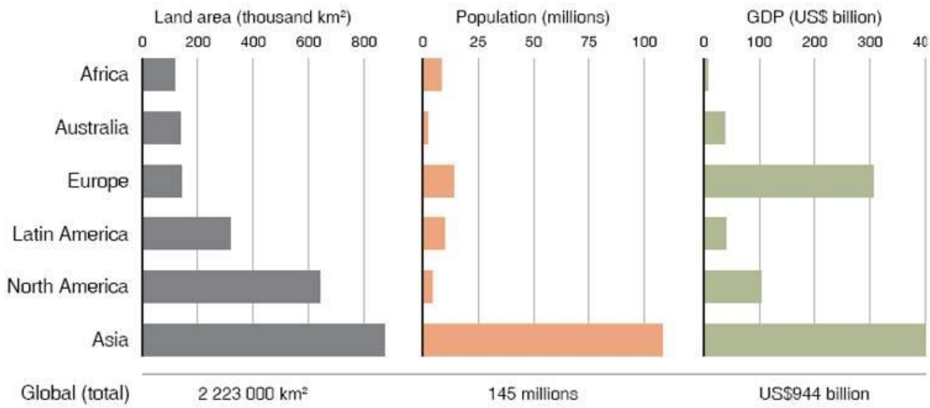

Fig. 5.13. Consequences of a one-meter sea-level rise in relation to continents (Source: Anthoff *et al*. 2006 in: UNEP, 2008)[55]

In this case, 18% of Bangladesh and 80% of the Marshall Islands would be covered by water (it is thus no coincidence that small islands threatened by such disasters were active at the Berlin Climate Conference in 1995). However, there are coastal areas where land is sinking for geological reasons, therefore a greater rise in sea level can be experienced there. Those who live in such areas are constantly struggling with the rising sea. The most well known of these areas is the Netherlands and its surroundings. In the Netherlands, dam systems and continuous drainage and filling up of depressions are used to combat the rising sea level. The success of this depends, besides technical development, on the hardly predictable (possibly cumulative) effects of natural forces. In addition to

[54] Melting sea ice does not result in sea-level rise, since ice floats on water and the phenomenon of isostasy applies.

[55] The figure shows the state in the early 2000s. The population of Asia has grown considerably since then. At https://climate.nasa.gov/interactives/climate-time-machine under the 'sea-level' menu you can find interactive maps of more of Earth's sea shores, and can adjust and investigate the territorial consequences of sea-level change.

the above, one should not forget that even a strong, persistent onshore wind can cause a (temporary) sea level rise of 1-2 meters.[56]

The warming of seawater may result in damage to coral reefs in tropical areas. The latter represent the second most species-rich ecosystems after tropical forests in the world, and are the most species-rich areas of the ocean. Coral areas occupy only 0.3% of the area of the sea, but one quarter of all species live there (for example, two-thirds of all seafish). Corals are very sensitive to changes in external conditions. If the surface temperature of seawater exceeds 28 °C during the warm season, the coral polyp 'gets rid of' the algae that lives on it and the coral bleaches (turns white). If the phenomenon persists, the coral reef dies, as the algae provide them food that they create through photosynthesis. The phenomenon was described in the 1870s, but the mass destruction in the Pacific in the 1980s highlighted the problem. The process became even more intense in the 1990s. The further rise in surface temperatures (sometimes to over 30 °C) caused 60-70% of the coral reefs to die over a huge zone (from Africa to South India) in the Indian Ocean. Between 1998 and the end of the 2000s, 27% (!) of the coral reefs on Earth died. The greatest damage ever was experienced in 1998, at the time of the biggest El Niño - La Nina event. Sixteen percent of coral deaths are associated with this nine-month event. The changes are spatially differentiated, with the fastest process of destruction developing in the Indian Ocean, but they continued later too.

Coral reef destruction due to seawater warming has also continued in recent years (when 3-4 °C anomalies were observed for several months). The importance of the problem was also highlighted in 2008 which was designated the 'Year of the Coral'. Of course, this symbolic activity did not solve the problem and further dramatic coral degradation was observed during the El Nino period in 2015-2016. Greatest attention has been paid to the Great Barrier reef in Australia, although other tropical areas were significantly degraded worldwide too (Japan, Hawaii, Florida, etc.). Up to 50%, 73% and 90% of coral reefs in Hawaii, in the Maldives (between March and May 2016), and in Kiribati were damaged by a warm-water period lasting over ten months, respectively. Some claim that our planet has lost half of its 'Tropical Rainforests of the Sea' over the last thirty years, but if the process continues it will be 90% by 2050.

Since corals have tolerated higher temperatures for hundreds of millions of years, scientists think that the more rapid changes are the reason for the destruction. Coral bleaching affects not only corals but the other species that live in symbiosis with algae. In areas close to land, corals are also endangered by pollutants (mainly nitrogen and phosphorus). These create poor oxygen and light conditions for corals via the phenomenon of 'algal blooms'.

[56] In the case of Lake Balaton, with its relatively small size, water fluctuations of 60-70 cm have been experienced due to the strong wind.

Seawater acidification

Among the greenhouse gasses released into the atmosphere, the huge amount of carbon dioxide contributes to environmental problems, but not only by warming the atmosphere. As can be seen in Fig. 5.7, 8.7 Gt carbon dioxide is absorbed into the oceans, resulting in their acidification. Measurements show that the carbon-dioxide content of seawater follows atmospheric changes (however, the changes are of greater amplitude and less by 20 ppm in the seawater around Hawaii), and result in the slow acidification of seawater (Fig. 5.14). However, the slow decrease in the pH of seawater (a decrease of 0.02-0.03 over twenty years) has been enough to disturb the production of the calcium-carbonate skeletal elements of calcareous organisms.

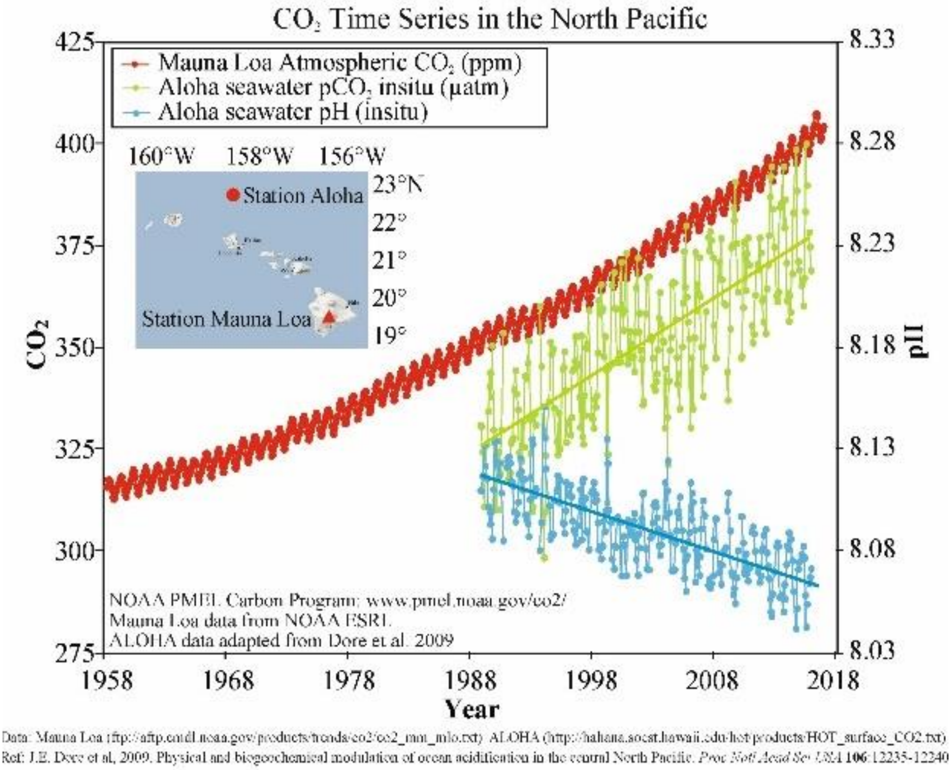

Fig. 5.14. Seawater acidity and atmospheric and seawater carbon dioxide time-series near Hawaii over the past few decades
(Source: NOAA PMEL,[57] supplemented)

[57] NOAA's PMEL programme has highlighted the important consequences of a CO_2 increase in the atmospheric that affects seawaters. Some results can be found at: https://www.pmel.noaa.gov/co2/story/Ocean+Acidification and on the related websites.

El Niño

When climate-related anomalies (e.g. droughts, floods, hurricanes, extreme cold, etc.) affecting areas of greater extent have been experienced in the past 2-3 decades, El Niño was very often blamed. This natural phenomenon occurs due to a heat anomaly resulting from the interaction between the (Pacific) ocean and the atmosphere, and its regular occurrence was detected decades ago.

Under normal conditions (as a result of the Earth's atmospheric circulation and the related sea circulation) a significant difference in air pressure develops: higher pressure over the south-eastern Pacific Ocean and low pressure over Indonesia and North Australia. Under such conditions the pressure difference contributes to the formation of eastern trade winds along the Equator. The winds take warm surface water to the western Pacific, and in the meanwhile raise sea level by approximately 40 cm. The warm seawater flow extends down to about 200 meters in depth in the western Pacific. Along the South American shores, from where the trade winds take warm water away, the border of the cold and warm water is near the surface due to cold water upwelling.

Near Indonesia, trade winds meet with western winds, the warm and humid air rises, and heavy rains are created. The warm air flows eastwards in higher parts of the atmosphere, and sinks above the Middle or Eastern Pacific Ocean resulting in dry weather. Under normal conditions the sea temperature along the shores of the Eastern Pacific Ocean is 6 °C less than near Indonesia. At irregular intervals the pressure difference weakens between the two regions. The easterly trade winds weaken, and sometimes turn. Therefore, sea temperature is higher than usual along the eastern shores, and lower along the western shores. This phenomenon is called the *El Niño.*[58] In this case, warmer and saltier water than usual reaches the shores of South America, worsening the potential for fisheries. Since active weather events are related to the warm surface waters near the Equator, tropical storms (typhoons, hurricanes) evolve further eastward than usual. Along the western shores of America, the weather becomes variable and the frequency of hurricanes increases. In the meanwhile, severe droughts evolve in south-eastern Asia and Northern Australia, and wildfires are more frequent. This also means that, apart from the severe droughts, the amount of precipitation in an El Niño year is the same, but its spatial pattern changes: it causes flooding on remote land, and rain falls over the ocean.

[58] In scientific literature, the term ENSO (El Niño and Southern Oscillation) is used to refer to the fact that the circulation is connected to atmospheric processes. According to experience, the phenomenon occurs every 2-10 years and can last for up to twelve months.

El Niño is a well-observable natural phenomenon; its changes influence coral bleaching. As mentioned before, it played a significant role in the coral reef degradation of the past two decades (1982–1983, 1997–1998, 2015–2016). The phenomenon cannot be blamed for all climate-related natural catastrophes, however. As a part of the atmospheric circulation, changes are influenced (and sometimes forced) by global warming.

The Great Ocean Conveyor Belt

Seawater covers approximately 70% of the Earth's surface, thus its processes basically determine the climate of our planet. Many people think that the slow rise in seawater temperature due to an increase in the concentration of greenhouse gasses involves a simple linear change ('it might be warmer in the future'), and are not concerned about further changes. Those who think in a more responsible way may encounter environmental hazards described in the light of the most recent research results and emphasize that *warming cannot be described by linear trends*.

One important question related to future climate change on Earth may have been clarified in the second half of the 1990s: researchers succeed in finding an appropriate explanation for the quick climatic changes of the glacial periods. It has long been known that there were significant climatic fluctuations in the Quaternary period of Earth's history when cold glacial and warmer interglacial periods followed each other (in the Alps, four glaciation periods can be distinguished based on glacial changes). At the beginning of the 1990s, the investigation of Greenland samples of ice-core drilling to depths of three thousand meters provided a detailed record (annual data for the past forty-five thousand years) of temperature changes during the past one hundred and ten thousand years.[59] The results highlighted that climate fluctuations were more frequent and rapid than thought before. The work of the Swiss researchers who processed the ice cores attracted the attention of Broecker, an American ocean and climate researcher, to the fact that the changes are similar to a process of oscillation between two states. It was concluded that the events observed in Greenland might be the consequences of changes in oceanic circulation.

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[59] Based on the ratio of oxygen isotopes 16 and 18 in ice, scientists can determine its age. In Antarctica – near the Russian Vostok base – environmental data for about 440 thousand years are available based on ice-core samples from 1998. At the Dome C base in 2004 ice-core samples were found to be 890 thousand years old; furthermore, near the Allan Hills (in the Allan Mountains) samples of ice 2.7 million years old were also found in 2010 and 2015 from a less thick ice sheet (according to results published in 2017).

Based on paleo-climatological data and an investigation of ocean circulation (e.g. using radioactive traces) it was revealed that there is continuous (surface and deep-sea) circulation between the large ocean basins called the oceanic conveyor belt (or simply, the 'Broecker conveyor belt') (Fig. 5.15). This flow, currently transporting water at 20 million m^3/sec (one hundred times more than the flow of the Amazon, and equivalent to global precipitation), creates a positive anomaly of 5-10 °C in the North Atlantic, thus its termination would lead to significant cooling of that landscape. It might have been the periodic stopping and restarting of this circulation that caused the rapid fluctuations recorded in the ice-core samples from Greenland and the Antarctic (see Fig. 5.5). But what could have been the reason for the shutdown and restart of the great ocean conveyor belt? 'Where is the switch located?'

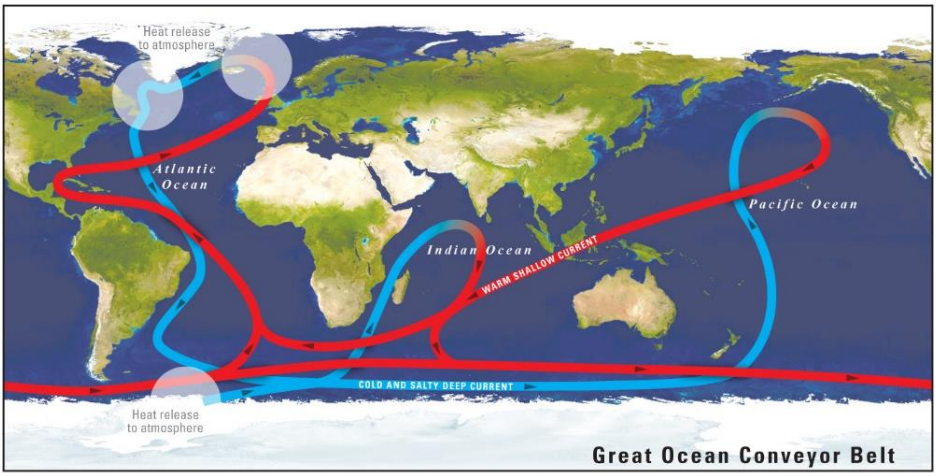

Fig. 5.15. Broecker ocean conveyor belt (Source: IPCC 1996, based on Broecker)

Detailed investigation of the circulation revealed that the conveyor belt, which is *driven by the changing temperature and salt content of seawater*, is a thermohaline system of circulation. The warm flow (the North Atlantic Current) towards the northern part of the Atlantic Ocean, which has a temperature of 12-13 °C near Iceland, cools down to 2-3 °C as a result of cold currents and heat loss due to high levels of evaporation,[60] while its salt content increases. Therefore, its density becomes higher compared to that of deep-sea water, and it sinks deep down and continues flowing southwards. The cold, deep seawater of near constant temperature enters the Pacific Ocean through the southern basin of the Atlantic and Indian ocean, where the upwelling cold current (the reason for this

[60] This is the reason for the cyclones that have a major role in the development of precipitation conditions in Europe.

upwelling was described earlier in the discussion of the El Niño phenomenon) continues westwards and warms up, closing the circulation loop. The most critical, fragile section of this process is the North Atlantic Ocean. Here, surface water sinks into the deep sea due to relatively small differences in salt content. If any fresh water supply diluted the ocean in this region, the circulation process might stop.

Broecker had three theories about what might reduce the salt content: a) an increase in precipitation, b) an increase in the discharge of large (Canadian and Siberian) rivers with indirect input to the region, c) melting Arctic ice. The latter may be strongly but indirectly connected to changes in the greenhouse effect too. According to Broecker, if warming causes melting in polar areas, freshwater[61] inflow will dilute the circulation and thus reduce its salt content to below the critical value for sinking and the conveyor belt will stop. As a result, the temperature in the surrounding area will decrease (since the warming impact of the circulation will terminate), which will stop the melting process; moreover, the amount of ice will increase. Due to this, the salt content will increase so much that the conveyor belt will restart (as if someone had switched on a conveyor belt). This process may be repeated multiple times. As a result of the cooling process, the snow line[62] may decrease significantly on land. The advance and retreat of glaciers cannot follow such rapid changes, so their role is mainly geomorphological, based on which we can draw conclusions about phases of glaciation.

Broecker's research has very important consequences*: if the great ocean conveyor belt stops, this will be followed by rapid climate change.*[63] Expected temperature changes of up to 5-10 °C (both negative and positive) would have serious ecological and economic consequences. There would also be a significant change without the shutdown of the ocean conveyor belt if the sea ice in the northern hemisphere melted as a result of warming (this happened four million years ago for the last time, when global temperatures were 4-5 °C higher than they are nowadays). Although there are still many details that are unclear about the role of the big conveyor belt, its past impacts show that the process is not scientific fantasy.

The slowing down, transformation, or the (temporary) disappearance of the mechanism of oceanic heat exchange would cause socioeconomic problems that can hardly be estimated at today's level of economic development. Rapid changes in Arctic ice cover may therefore pose a serious risk in the near future.

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[61] During ice melting, freshwater enters seas and rivers, since the rainwater from which it is formed is freshwater.

[62] Broecker prepared a reconstruction of this for the continent of America.

[63] This environmental problem was the basic idea in the film *The Day After Tomorrow*, released in 2004.

Changing precipitation conditions

As we have seen before, global data are relatively consistent about climate-change-related processes related to temperature changes (at least in direction), but in the case of precipitation varying trends have been experienced over centuries, and even during shorter periods too (Fig. 5.16). It is clearly observable that Southern and Eastern Europe, two-thirds of Africa, Eastern and South-eastern Asia, East Australia and Amazonia have experienced a decrease in the amount of precipitation in the past half-century. These changes – with natural fluctuations – are part of a trend. According to the aforementioned figure, it is also clear that certain areas have had more than average precipitation (central areas of the USA, Patagonia, Scandinavia, huge territories in Russia and Western Australia), although according to long-term modelling a decrease in precipitation will be more characteristic of land areas in the future. Furthermore, the decrease will intensify in the next decades in areas that are of great importance to humanity.[64]

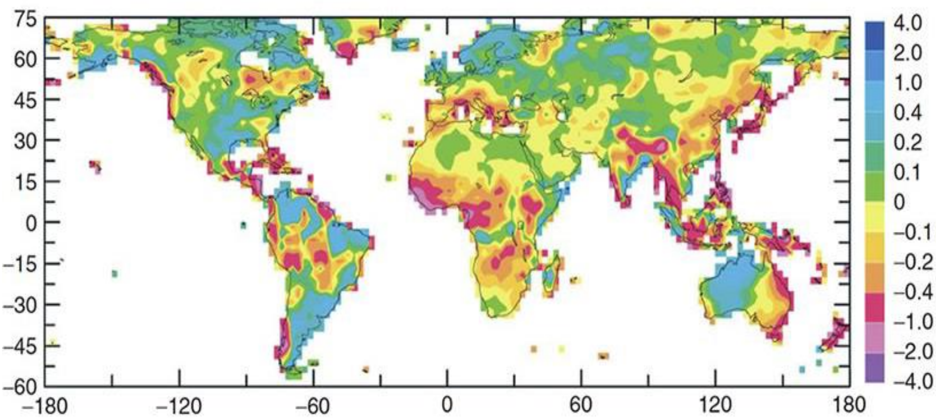

Fig. 5.16. Precipitation trend in millimetres per day (1950–2008)
(Source: Dai 2010)[65]

Except for India, the most populated regions will be affected, and the most of the rainforests, including the Amazon region, that play a critical role in Earth's CO_2 budget. The catastrophic effects of this phenomenon were demonstrated

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[64] At the time of the compilation of this book, changes for three time periods were available at: https://www2.ucar.edu/atmosnews/news/2904/climate-change-drought-may-threaten-much-globe-within-decades

[65] The data here are measured data. The figure is available at: https://www.climatecommunication.org/new/features/extreme-weather/precipitation-floods-drought/

in 2010.[66] In the Amazon region an area of approximately three million km^2 was hit by significant drought which led to an increase in CO_2 emissions of eight billion tonnes, only slightly less than US and EU emissions from fossil fuels in 2016 (5.3+3.4 Gt). Moreover, there was also a severe drought in 2005; however, at that time 'only' 1.9 million km^2 were affected. This fact also indicates that *global climate change can dramatically influence the greenhouse gas budget through natural 'channels'*. Precipitation that does not fall on the continents falls over the oceans, but cannot be utilized by humanity.

Expansion of deserts

As a consequence of the global warming of the atmosphere and changing precipitation conditions, the first comprehensive environmental changes occurred in dry, desert and semi-desert areas. The phenomenon known today as desertification can be observed on all continents, but it causes the greatest damage in Africa, Asia and North America. The importance of the problem is demonstrated by a UNEP report,[67] according to which almost one-quarter of all land area (33.7 million km^2) and roughly five hundred million people are affected. The situation is worst in Africa where two-thirds of the population of the continent live in drought-prone areas. The relatively early recognition of this phenomenon is evidenced by the fact that the first desertification conference was held within the United Nations Environment Program in 1977 (the action plan that was elaborated had very poor results in the absence of adequate financial support). Based on research into the causes of *desertification* it became clear that *it is not simply a natural phenomenon but a joint consequence of natural, social and economic processes.*

The natural causes of desertification, beyond precipitation conditions, are closely related to the global warming of the atmosphere; however, the process is faster and more obvious than climate change. Its spread is fairly measurable: as a result of the process some six million hectares of land have become desert, and a further twenty-one million hectares have become unsuitable for economic purposes in the last third of the twentieth century. According to recent research, annual losses of twelve million hectares of production area[68]

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[66] The lack of precipitation intensified in the following years: https://imgs.mongabay.com/wp-content/uploads/sites/20/2016/07/01195859/southamerica_mdl_2005-2016.png

[67] The Fourth Global Environment Outlook (2007), available at: http://web.unep.org/geo/assessments/global-assessments/global-environment-outlook-4

[68] https://www2.unccd.int/publications/desertification-invisible-frontline-second-edition (2014)

are occurring. Over the past decades, dry periods have become more frequent in many areas on the planet.

In the Sahel region, the area most affected by the problem, extreme dry periods have become increasingly permanent over the past century. From a more detailed study of the main causes it became clear that increasing water shortages affected this area most, although this was only one of the reasons for most of the desertified areas. For example, in Africa the severe drought in the 1910s did not cause hunger as much as the droughts which occurred after the 1970s did. The reason for this is that the very poor vegetation is particularly sensitive to environmental impacts. In these drought-prone areas, nomadic and semi-nomadic farming had been practised for centuries and the sparse population followed the seasonal changes of the humid belt. Later, however, in the southern areas of the so-called 'sub-Saharan belt', the increasing population settled and started engaging in permanent agricultural activity (millet, sorghum, meat and milk production). This farming – together with a decline in mortality rates – resulted in rapid population growth. In less than thirty years the population doubled, and its food demand could only be met (for some time) by increasing the number of livestock. There were certain areas (e.g. parts of Sudan) where the livestock count quadrupled over ten years. Ecologically fragile areas could not tolerate overgrazing: vegetation could not be regenerated, and the loose soil was irreversibly damaged by erosion and deflation in a short time. Other contributing factors included deforestation (for firewood and animal food), the burning of scrub, the further environmentally harmful impact of local wars, and the unfavourable trade policy of certain countries (which contributed to a decline in otherwise weak agricultural conditions). In some big cities dramatic changes occurred. Following the price boom in hydrocarbons in the early 1980s, charcoal consumption increased significantly in Khartoum, Sudan's capital; deforestation advanced southwards at 15-20 km per year on average (up to 400 km in the 1990s) and the Sahara expanded 5-6 km per year to the north-west.

An increase in water consumption can also contribute to expanding desert areas in some landscapes. Such a process is observed in the environment of Lake Chad and in Asia along the Aral Sea, where due to the huge use of irrigated water a major part of the former lake surface has become a desert (see later, Chapter 6.1.2).

The importance of the role of local society in the desertification process was pointed out by French research in Algeria.[69] By evaluating satellite images, researchers were able to distinguish between natural and anthropogenic changes. It was also revealed that under similar climatic conditions farms that

[69] https://hal.archives-ouvertes.fr/tel-01250719/document

used traditional farming practices did not suffer from the process, while newer ones with more intensified management practices experienced increasing inefficiency and the desertification of landscapes.

Thus, the desertification process means almost irreversible damage to arid and semiarid areas with a fragile ecological balance due to climate change and unfavourable farming activities and, as a result, expansion of a barren desert across areas of poor fertility. The consequences include the need to increase the use of less and less fertile land (until its full degradation), an increase in famine, the migration of people, and local wars.

The role of volcanism in climate change

Over the last centuries, there has been much volcanic activity that significantly influenced the solar irradiation conditions on Earth for periods of 1-2 years. Atmospheric aerosols reduce surface-reaching radiation from the Sun to such an extent that the temperature can drop several degrees. The 1815 eruption of Mount Tambora in the Indonesian archipelago caused a half-degree decrease in the global temperature in 1816[70] to which 70 - 90,000 deaths are attributed due to famine. Earlier in 1257, the Samalas eruption in Indonesia was followed by a cooling of 2 °C, and a 0.8 °C decrease in temperature was estimated to have occurred as a result of the explosion of Huaynaputina in 1600 in Peru. Recently, the 1991 eruption of Pinatubo in the Philippines was followed by a 0.3 °C drop in temperature.

Volcanic eruptions have influenced climatic conditions only for 1-2 years, but this does not mean that they will not have a greater impact in the future. In Earth's history it was only 'yesterday' when Toba volcano in Indonesia erupted 75,000 years ago, releasing approximately 2800 km^3 of material into the atmosphere, much more than Tambora (80 km^3) or Pinatubo (5 km^3). Such large eruptions of supervolcanoes, besides their role in the climate, would also cause enormous physical destruction. It is important to note that individual volcanic eruptions do not cause climate change, but only ongoing periods of volcanicity.

5.2.4. Who or what is responsible?

In the previous chapters it was explained how many components and consequences of current climate change have been clearly identified, although the whole process is more complicated than was earlier thought. The long- and short-term impacts of natural processes (e.g. volcanism, precipitation variability) are associated with the consequences of human activity (which may be reckless, insufficiently considered, or forced). Some of the most important

[70] The temperature changes due to the Tambora eruption is illustrated here: https://www.youtube.com/watch?v=eJfMUW-Uidc

elements have been described in previous chapters, but when trying to solve these problems it would be good to know who is responsible.

It was described earlier how, in the last century, compared to the previous hundred thousand years, the amount of greenhouse gas has grown massively. Over the last half million years the atmospheric concentration of CO_2 was always below 280-295 ppm. This decreased to 272 ppm during the minimum temperatures of the Little Ice Age, and, perhaps also due to the industrial revolution, it increased slowly (to 286-288 ppm) by the last third of the nineteenth century. Accelerating growth (to about 310 ppm) was experienced until the Second World War, corresponding to an annual increase of approximately 0.3 ppm. Growth has since accelerated, and has already exceeded 2 ppm per year over the last 1-2 decades (Fig. 5.17). When the CO_2 emissions of the last half century are considered, the role of human influence is hardly questionable.

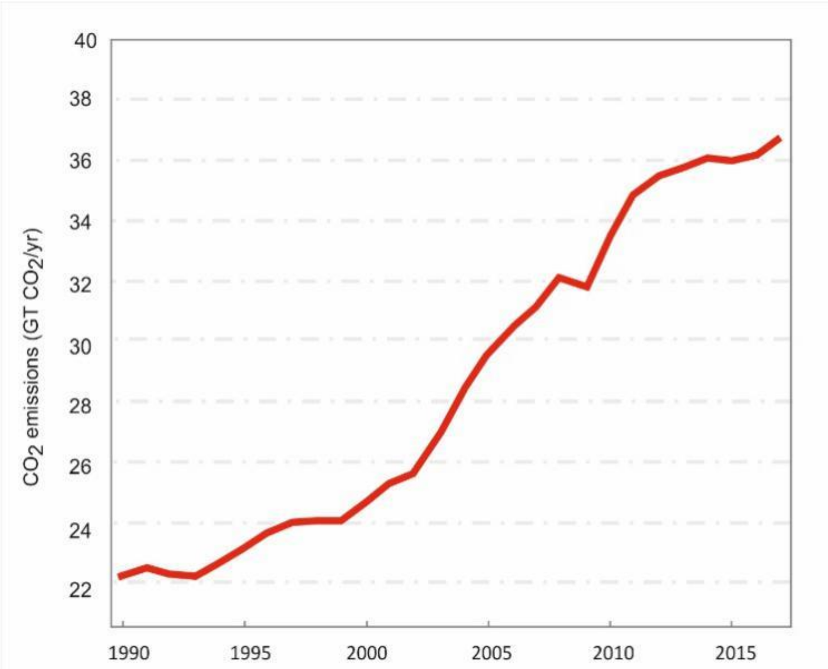

Fig. 5.17. Global CO_2 emissions (1900–2017) (Gt/year)
(using CDIAC and GCP datasets)

In terms of the sectors or countries that have caused the previously discussed quantitative changes, it can be concluded that there have been significant changes in the last half-century. Total CO_2 emissions have increased more than one-and-a-half times over the past quarter of a century, and today the four largest emitters (China, USA, the EU, and India) account for 59% of these. Since 1960 there has been a huge redistribution of responsibility between these countries. At the end of the 1980s, China's emissions did not amount to those of the US or EU. Subsequently, the dynamically developing Chinese economy, taking advantage of all the benefits of globalization, has been the largest CO_2 emitter since 2006, and its emissions surpassed those of the US and EU combined in 2016 (Fig. 5.18). Besides this great Chinese growth, the fact that the EU has been gradually reducing emissions since the end of the 1970s has also played a role in the process, as has the decline in the emissions of the US following the economic crisis in 2008. China's emissions have been stagnating since 2013 (due to a slight downturn in economic growth). At the time of writing this book, a very illustrative video[71] showed China's prominent role (besides the USA and the EU) in emitting CO_2. The change in atmospheric CO_2 concentrations in the period 2011-2012 reflects the emitters, the mixing process, and the fact that over the two-year period a change of 8-10 ppm in the northern hemisphere occurred, while in the southern hemisphere a decrease of 4-5 ppm was experienced. It is clearly observable that the increasing CO_2 concentration in the south is also caused by emissions from northern industrial sites following a period of a time. Figure 5.19. illustrates the two characteristic slides from the animation.

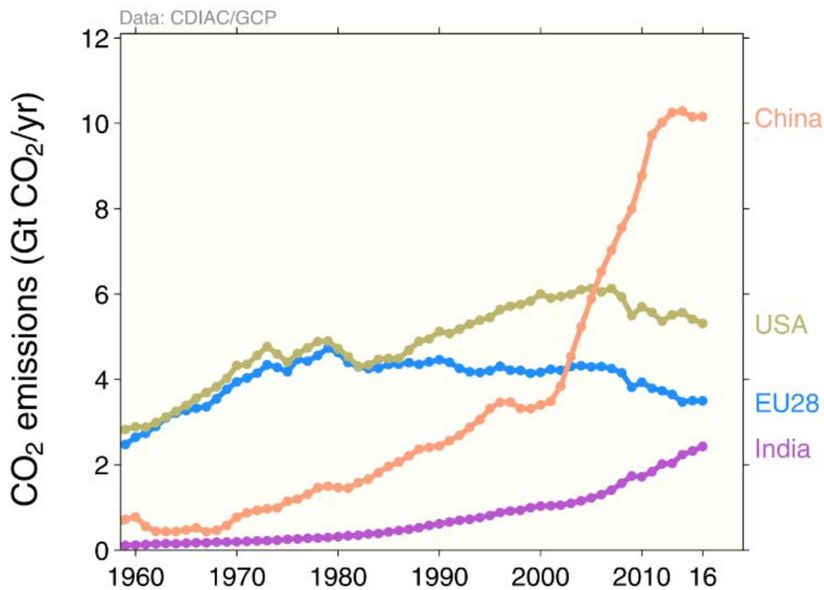

Fig. 5.18. Top emitters: fossil fuels and industry (1960–2016) (Source: GCP 2017[72])

[71] The video is available at: https://www.esrl.noaa.gov/gmd/ccgg/trends/ff.html

[72] GCP 2017, demonstrating the details, is available at: http://www.globalcarbonproject.org/carbonbudget/index.htm

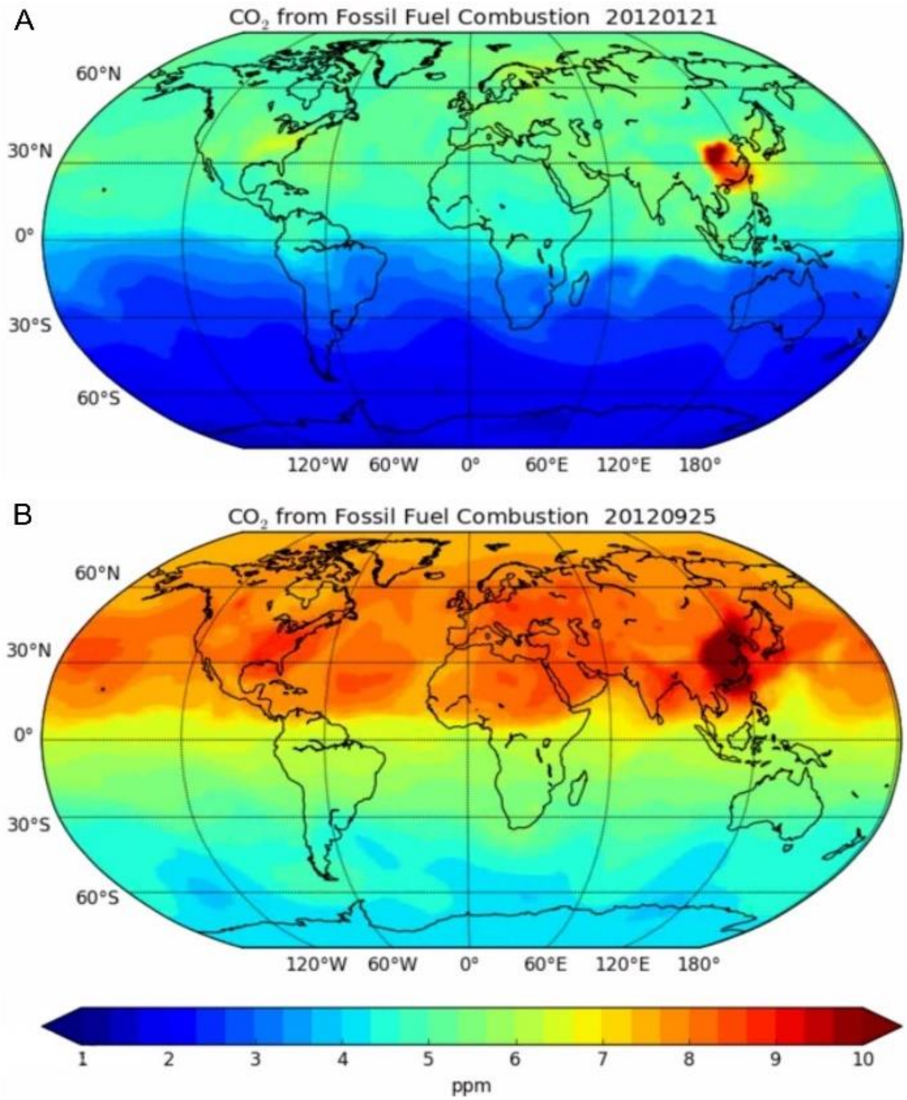

Fig. 5.19. Increasing atmospheric concentrations of CO_2 due to emissions from fossil-fuel combustion between 1 January, 2011 and 21 January, 2012 (A) and 25 September, 2012 (B) (Source: NOAA ESRL)

Although China is aware of its role as the largest greenhouse gas emitter, it has tried to explain how it has less responsibility by pointing to its lower emissions per capita compared to the developed countries. It is a fact that the United States is the largest among the major emitters per capita (four times the world average), but since the beginning of 2010 China has emitted more than the EU average (over one-and-a-half times the world average) (Fig. 5.20).

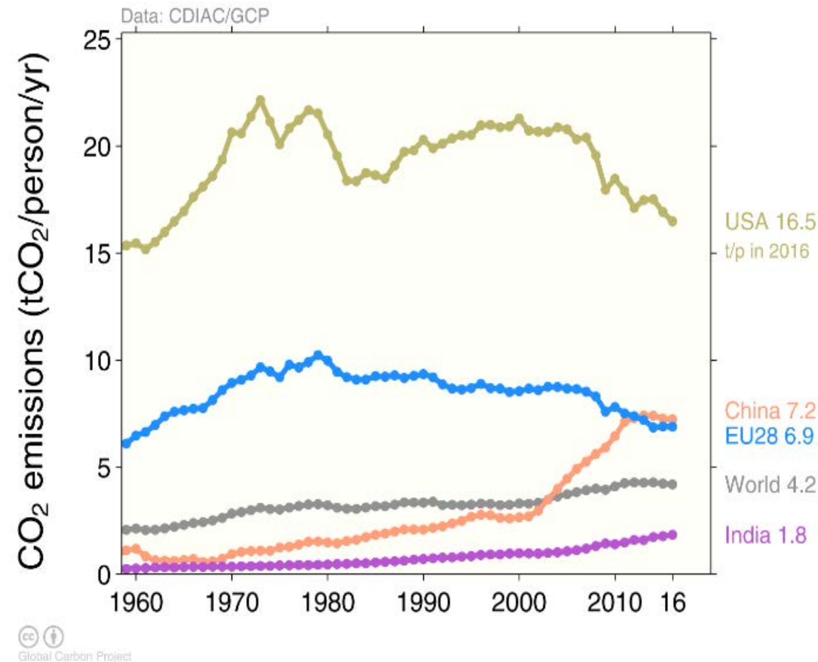

Fig. 5.20. CO_2 per-capita emissions of the top emitters between 1960–2016 (tCO_2/year/capita) (Source: GCP 2017)

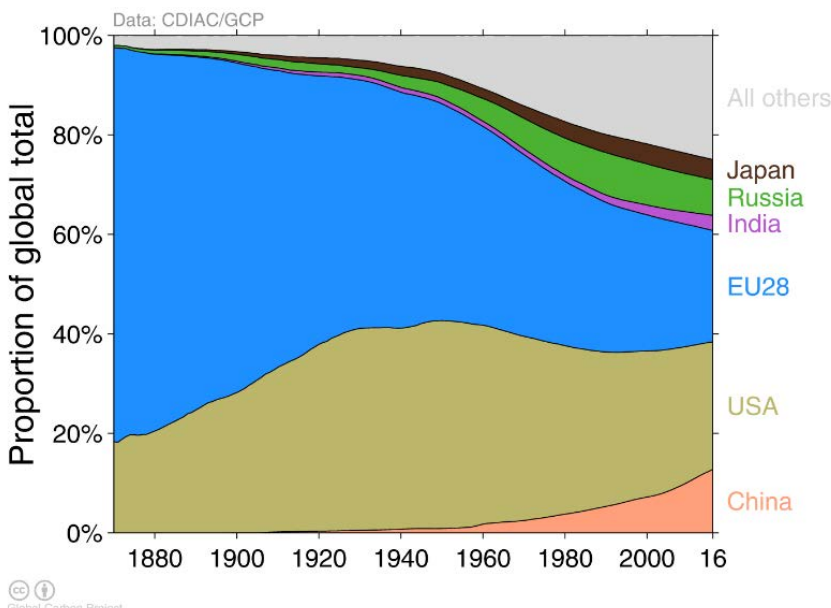

Fig. 5.21. Historical cumulative emissions by country (1870–2016) (Source: GCP 2017)

Within a research programme focusing on the recent changes in atmospheric carbon dioxide (the Global Carbon Project[73]), the historical responsibility of the major emitters was calculated retrospectively back to 1870. Based on the cumulative emissions (Fig. 5.21) it is clear that in the last third of the nineteenth century Europe accounted for three-quarters of all emissions. By the middle of the twentieth century, the US was approaching the EU level of emissions (nearly 40-40%). By 2016, the difference between the historical responsibilities of the countries had been significantly reduced (USA 26%, EU28 22%, China 13%, Russia 7%, Japan 4% and India 3%).

Assessment of the role of different economic activities over the past half-century shows that in the early 1960s there was no significant difference between the CO_2 emissions associated with fossil fuels and cement production, and the emissions related to land-use changes (58% and 42%, respectively). But by 2016 this had changed considerably (88% and 12%, respectively). During the period 1960–2016 the role of land use stagnated or slightly decreased (from 6 Gt/year to around 5 Gt /year[74]), while emissions associated with industrial activities had quadrupled (from 9 Gt/year to 36 Gt/year) (Fig. 5.22).

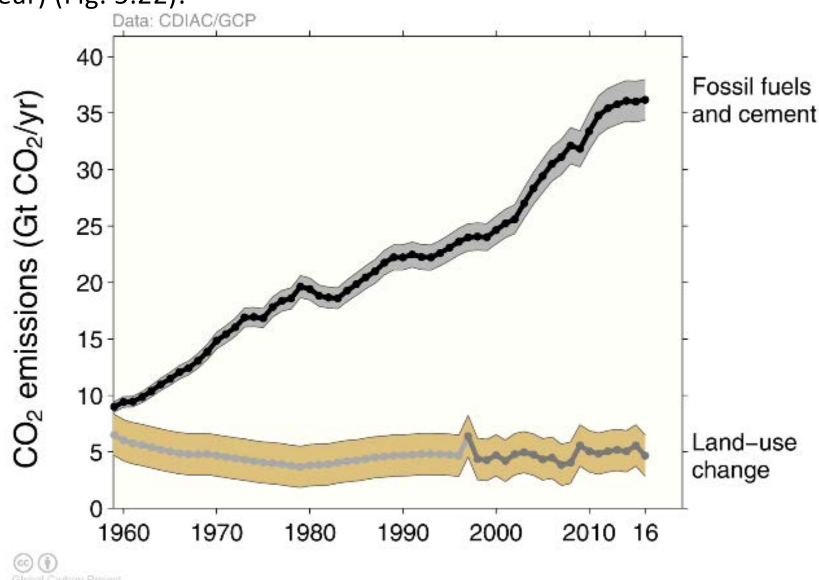

Fig. 5.22. CO_2 emissions due to fossil fuels and cement production, and Earth's land-use changes (1960–2016) (Gt/year) (Source: GCP 2017)

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[73] A detailed summary from November 2017 is available at:
http://www.globalcarbonproject.org/carbonbudget/index.htm

[74] It is observable in the figure that the long-lasting Indonesian forest fires in 1997 released approximately 2 Gt CO_2 into the atmosphere.

Assessment of CO_2 emissions from energy and cement production indicates that at the beginning and the end of the sixty-year period of investigation, coal-related emissions were highest. At the end of the 1960s, crude oil took the leading role, but due to the significant increase in its world market price (as well as the increase in hunger for energy), coal consumption increased dynamically in around 2000 and since 2005 the use of more polluting fuels has come to the fore (Fig. 5.23). In 2016, the emissions attributable to each factor were: coal (40%), oil (34%), gas (19%), cement (6%), flaring (1%).

Major effort is being made throughout the world to replace the energy sources that increase greenhouse gas concentrations with renewable energies; however, due to their slow uptake and the further use of fossil fuels, the amount of atmospheric CO_2 will unfortunately increase for a long time (see later in Chapter 16.2.2).

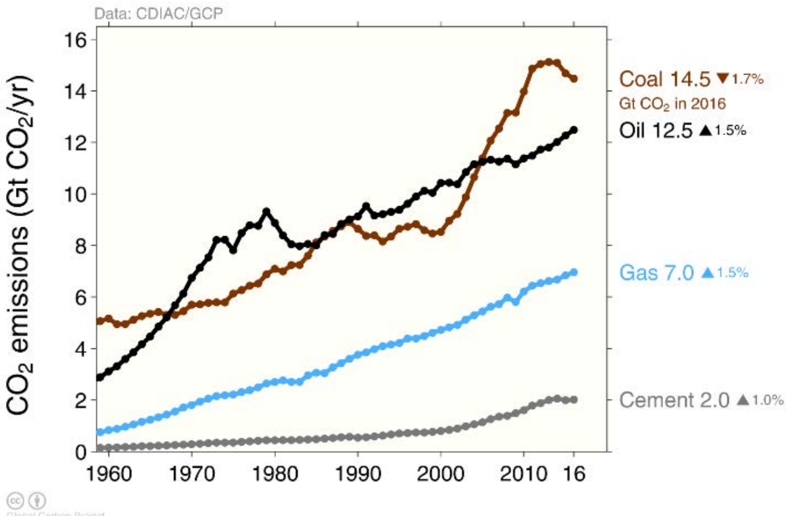

Fig. 5.23. Emissions from coal, oil, gas, cement (1960–2016)
(GCP 2017, data source: CDIAC)

The research concluded that, in the last one-and-a-half centuries (since 1870), the use of coal, crude oil, natural gas, and cement production increased atmospheric CO_2 concentrations by 92, 70, 30, and 3 ppm, respectively. The unfavourable effects of land use were roughly compensated by surface carbon sequestration, and the absorption of the oceans reduced the concentration of atmospheric CO_2 by 69 ppm.

Since economic activities have become more efficient, CO_2 emissions per unit of economic output have been reduced worldwide, but there are significant differences between countries. In 2016, from among the largest emitters, Russia and China emitted 2.5 times more CO_2 (0.53 $kgCO_2$/ USD) per unit than the developed EU countries, and nearly twice as much as India and the USA.

The Global Carbon Project also undertook a detailed analysis[75] of the atmospheric cycle of *methane*, which plays the second largest role in the greenhouse effect. The role of each factor can only be quantified within a relatively broad range. The main reason for this is the uncertainty surrounding emission estimates. Considering the emissions between 2003 and 2012, the role of anthropogenic effects slightly exceeded natural ones (Fig. 5.24). However, the global warming of the Earth's surface may substantially increase methane emissions especially in areas with permafrost, and the situation may even be reversed in the future. Total emissions exceeded total sinks by about 10 Gt per year, resulting in a continuous increase in the role they play in the atmosphere (see Fig. 5.4, above).

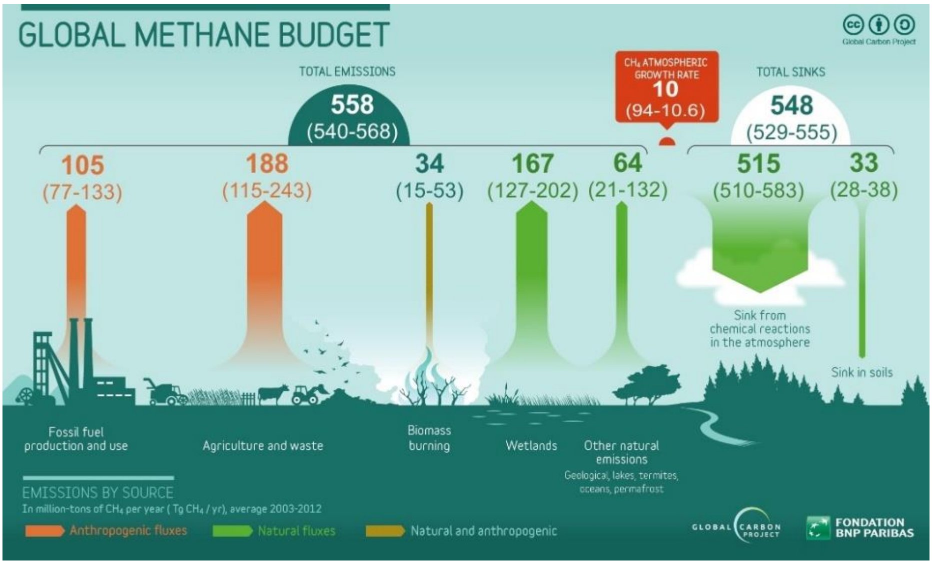

Fig. 5.24. Global methane budget (Source: GCP 2017)

5.3. The ozone problem

5.3.1. The background to the changes in ozone concentration

When someone meets the word 'ozone hole' today, they hardly even need to ask what it is, even though this atmospheric phenomenon was discovered only in the mid-1980s. The fact is that the depletion of the stratospheric ozone layer, with its particular importance for life on Earth, almost instantly mobilized decision-makers who in 1985 tried to protect it through an international convention (see later in Chapter 16.2.1).

[75] http://www.globalcarbonproject.org/methanebudget/16/presentation.htm

Ozone plays an important role in the Earth's atmosphere. Stratospheric ozone (about nine-tenths of total ozone) has an UV-filtering role that is essential to organisms: it completely filters out harmful UV-C radiation (wavelength <290 nm) and significantly reduces the level of also harmful UV-B radiation (290–320 nm). However, tropospheric ozone produced near the surface is an aggressive greenhouse gas that has oxidizing effects and is a typical component of photochemical smog, thus its present increase is harmful.

Oxygen is the second most common gas in the atmosphere. Most oxygen in the air is present in the form of diatomic gas molecules. This O_2 molecule can be transformed into a triatomic molecule, O_3, through a photochemical reaction (due to short-wave radiation from the Sun). However, this is easily decomposed (at 20 °C with a half-life of three days). Its amount is determined by the combined role of *generation, transport, and decomposition*. During the Earth's history, an almost steady state was created in the stratosphere (at about 15-50 km altitude). The permanent ozone layer contains a constant concentration of ozone where ozone generation and decomposition is in balance. According to calculations, if ozone generation stopped, the current 3.3 billion tonnes of ozone in the atmosphere would decompose within two years. The vertical distribution of ozone shows that its maximum density (depending on the geographical location) is found at an altitude of 15 to 25 km (Fig. 5.25).

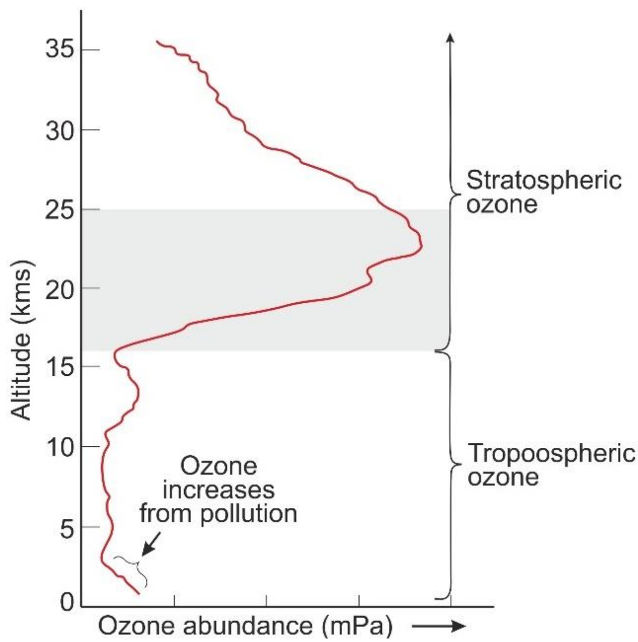

Fig. 5.25. Vertical distribution of ozone in the atmosphere, highlighting the temporal (spring) ozone depletion zone

Stratospheric ozone is measured in Dobson Units (DU).[76] Since ozone generation depends on intense UV radiation, the main area for its formation is the stratosphere above tropical regions. In theory, this should result in the thickest ozone layer being formed over the Equator. In reality, however, atmospheric cycles transport some of the ozone, thus, until the end of the 1970s, 250-260 DU was measured over tropical areas, while over the North Pole an annual maximum of 440 DU and over the Antarctic region 340 DU was characteristic. This apparent contradiction is solved by knowing that the ozone generated over the tropics is transported to the higher latitudes by the strong winds of early spring and the end of winter. In the northern hemisphere, the flows extend to the polar region, but in the southern hemisphere, the westerly winds at 50-60 degrees' latitude strongly restrict the location of the ozone to Antarctica. In its main features, this general spatial distribution is also characteristic nowadays (Fig. 5. 26).

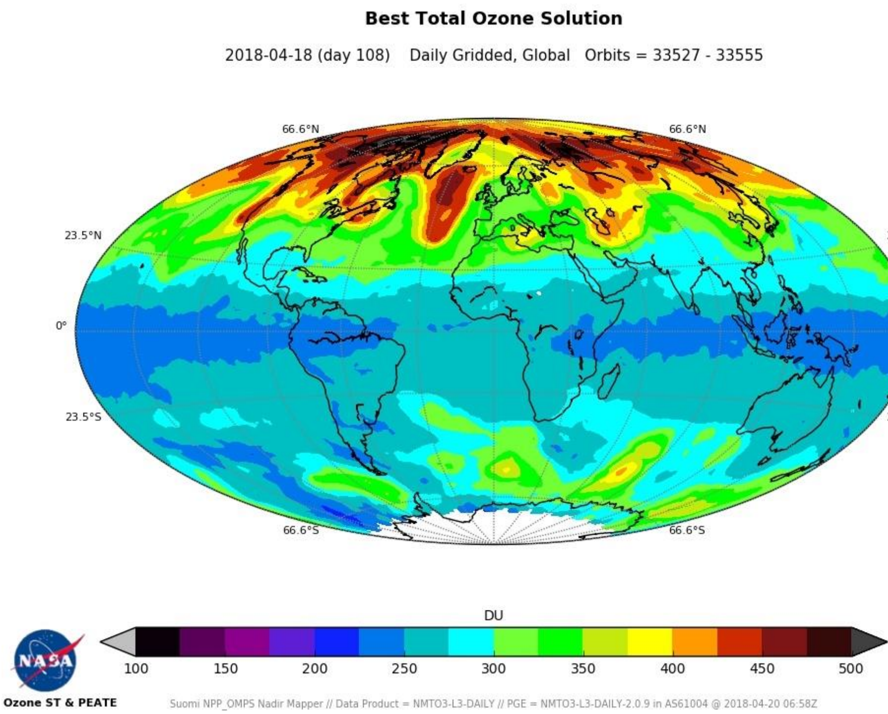

Fig. 5.26. Spatial distribution of stratospheric ozone, 18 April, 2018 (Source: NASA[77])

[76] One Dobson Unit means that the ozone content of the atmospheric layer corresponds to 0.01 mm under normal pressure at sea level. A typical column amount of 300 DU of atmospheric ozone is equivalent to 1 ppb. The abbreviation DU is used from now on.

[77] Map downloaded from https://ozoneaq.gsfc.nasa.gov/ on 20 April, 2018

Ozone is also formed near the surface (in the troposphere) from the chemical reactions of sunlight and certain pollutants. In contrast to common ideas about the phenomenon ('pleasing ozone-rich air'), ozone in the troposphere is an aggressive oxidant and, in addition, a greenhouse gas, a harmful atmospheric component. Photochemical oxidants such as ozone may also cause serious physical and mental impairment in concentrations of up to 0.5 mg/m^3.

Ozone therefore has two opposing roles in the atmosphere: in the stratosphere its UV-radiation-filtering effect is of vital importance for life, but its presence in the troposphere is harmful. Thus, it is an unfavourable trend that its concentration is decreasing in the stratosphere, and increasing in the troposphere.

Regarding its temporal characteristics, stratospheric ozone changes seasonally, while tropospheric ozone is characterised by daily changes (due to the difference in irradiation between the daytime and the night, and the daily concentration patterns of pollutants).

Surface surveying of the atmospheric ozone concentration started in Antarctica in 1956 and its satellite measurement began in the early 1970s (this became worldwide due to the launch of the Nimbus-7 satellite in 1978).

Some researchers (Molina and Rowland[78]) discovered at the beginning of the 1970s that, as a result of strong UV radiation, normally non-reactive and non-flammable chlorine compounds such as CFCs[79] produced in significant volume have the potential to initiate ozone depletion, but high importance was not attached to this fact at the time. The first alarming data emerged in 1983, when a low 180 DU was measured in the Antarctic in October. The 'bomb' exploded when British scientists (Farman, Gardinar and Shanklin) published satellite data in the journal *Nature* in May 1985 that showed a significant thinning of the ozone layer over the Antarctica. Although this was thought by NASA to relate to a measurement error for a short time, subsequent investigations confirmed the ozone depletion and traced it back several years. The researchers tried to find an explanation using theoretical approaches and detailed measurements too. It was first thought that it was merely an atmospheric mixing problem, but this idea was rejected in a short time, and the theory of Molina and Rowland relating to the potential for ozone depletion was increasingly highlighted.

[78] Molina, Rowland and Crutzen received the Nobel Prize in Chemistry for the theoretical clarification of ozone layer depletion in 1995.

[79] These materials, once considered safe, were produced from 1928 onwards and were commercially used in refrigerators following 1930. Later, they became popular as propellants in spray cans, and their use exceeded one million tonnes in 1988.

Researchers confirmed that two groups of Polar Stratospheric Clouds (PSCs) play a major role in stratospheric ozone depletion. In the first type, water precipitates (i.e. ice is formed) on condensation cores at temperatures below -85 °C. Among them – if larger ice crystals are formed during fast cooling – nacreous or 'pearl' clouds are characteristically created (these were named based on their colour due to their special refraction properties). The second group is characterised by slow cooling, thus the ice crystals are small, and the clouds thus created can hardly be recognised. A temperature of -78 °C is enough for their formation. In these clouds the presence of either nitric acid trihydrate (HNO_3. $3H_2O$), or nitric acid and sulphuric acid, or nitric acid is determining. Among PSCs only pearl clouds are easy to recognize; the other two types can be detected only with instruments. These clouds are not extraordinary phenomenon (pearl clouds have been identified for decades), but their significance has now increased as it is known that, during atmospheric mixing, ozone-depleting pollutants enter the stratosphere. In these clouds of very low temperature which serve as reservoirs, chlorine and bromine compounds[80] are bound up and accumulated, then later released due to the rising temperatures in springtime and are then temporarily decomposed as a result of UV radiation. After then participating in ozone depletion, they revert to their original state. Thus, they participate in ozone depletion as catalysts, and later can continue to play their harmful role again.

As detailed above, a very low temperature is needed for the formation of PSCs, which can evolve during the winter period over the Antarctic with its large ice mass. However, the ozone depletion of the compounds released from the reservoirs also initiates a feedback process: as ozone absorbs sunlight, it warms the atmosphere. If the ozone layer thins, the atmosphere warms up more slowly and PSCs can survive for a longer time, thus their impact can be greater.

By examining the temporal and vertical changes in ozone concentration and their relationship with temperature, the importance of the role attributed to PSCs can be confirmed.[81] Daily data from Antarctica show that the maximum concentration of ozone is usually in March (around 320 DU) following 300 DU in January, while its maximum concentration is found at an altitude of 18-23 km. At this time, the temperature is warmer than -40 °C at above 10 km. During autumn and winter, the air continuously cools down with the decreasing irradiation in layers

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[80] Bromine compounds can be found in fire extinguishers, and their combined effect is approximately one-fifth that of chlorine products.

[81] At https://www.esrl.noaa.gov/gmd/dv/spo_oz/movies/ Antarctic ozone animations can be found for each year following 2000, where temporal and vertical patterns (left-hand side of the graphs) of ozone concentration (blue column in the middle) measured in the South Pole are illustrated compared to the current temperature (right-hand side).

higher than 12-15 km (it remains at between -90 and -70 °C for at least four months, reaching its minimum in July). During this time, the ozone content decreases very slowly (it declines from the upper regions towards the lower ones), but it is still around 220 DU even at the beginning of spring (early September) in the southern hemisphere. In early spring, the temperature rises rapidly at an altitude of 15-30 km, dramatically speeding up the decline in ozone content. In just two weeks, the amount of ozone falls from 220 to 120 DU, while it is completely destroyed from mid-September to mid-October at 15-20 km. During this period (when the temperature rises above -87 °C and then -78° C), ozone-depleting gasses, accumulated during the previous months, are released from the PSC reservoirs. Increasing irradiation causes ozone to increase and the amount at the beginning of summer is around 250 DU. In terms of annual variation, there are several short periodic changes that indicate ozone transport from tropical regions.

5.3.2. Ozone hole

The significant thinning of the ozone layer is called the *ozone hole*. This is, however, a deceptive name, as it does not mean the complete absence of the ozone layer, but a major reduction of it. Currently, *researchers consider areas where the ozone concentration is below 220 DU to be parts of the ozone hole.*[82] Such areas occur near the South Pole each year in the beginning of spring in the Antarctic. The size and duration of the ozone hole has been increasingly alarming since the 1980s (Fig. 5.27).

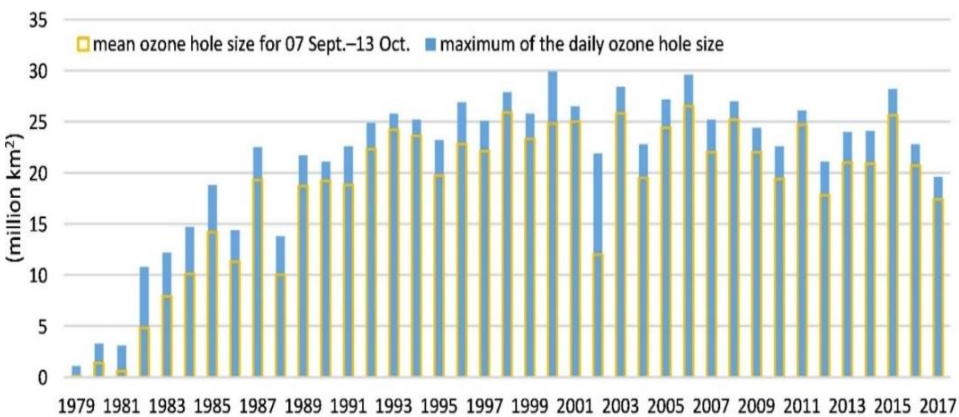

Fig. 5.27. Changes in the mean ozone hole size from 7 September – 13 October, and the maximum of the daily size of the ozone hole for each year between 1979 and 2017 (million km^2) (based on the NASA Ozone Watch data)[83]

[82] An agreed-on value, indicating that no lower amount was ever measured before 1979.
[83] Annual data can be found at: https://ozonewatch.gsfc.nasa.gov/statistics/annual_data.html (data from 1995 are from secondary sources due to technical problems).

The size of the ozone hole exceeded twenty million km^2 each year between 1989 and 2016, and in some cases was even close to thirty million km^2. Looking at the minimum values for ozone concentration following the first occurrence of the ozone hole in 1979 (Fig. 5.28), you will see that it continuously decreased from 225 to 92 DU until 1994 (with the only exception being 1988), and stagnated later at around 100 DU. It has shown a slightly tendency to increase since 2010. In the dataset, 1988 and 2002 may be considered favourable outliers. It is likely that temporary changes in atmospheric circulation made the transport of larger quantities of ozone from the tropics towards the South Pole possible.

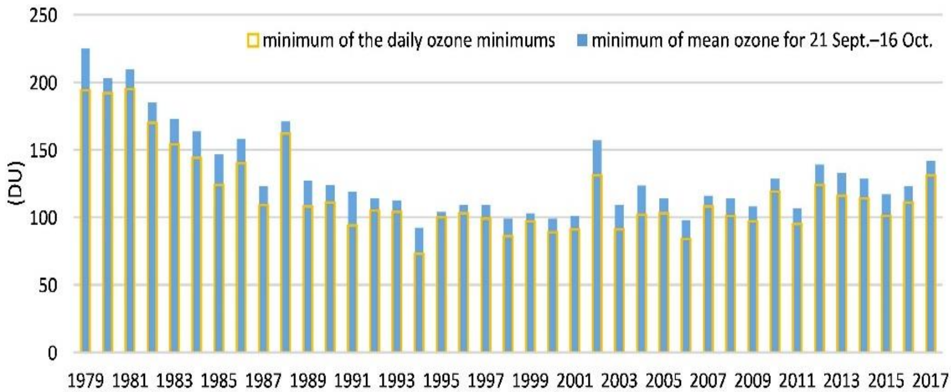

Fig. 5.28. Changes in the minimum of the southern hemisphere daily ozone minimums, and minimum of southern hemisphere mean ozone for 21 September–16 October for each year between 1979 and 2017 (DU) (based on the NASA Ozone Watch data)

The formation of the 'ozone problem' can be documented very well in time. Three characteristic dates are shown in Figure 5.29 where 1982 represents the early period of its development, 2006 is the year with the largest ozone hole, and 2016 is perhaps the date when the trend started improving. The diagrams show the changes in the ozone hole area. 1982 was the first year when its temporal formation could be assessed in the southern hemisphere. It developed then three times from mid-September to the end of October over an area of 2-6 million km^2. The largest ozone hole measured so far was identified in 2006 (Fig. 5.30). At that time, it evolved very fast and in the last third of August its area exceeded 20 million km^2, its maximum was 29.6 million km^2 on 24 September, and at the end of December it was still 10 million km^2. It then relatively quickly disappeared. Since 2012, it has been more likely to occur in the second half of August and end in mid-November. In 2010 and 2015, however, it remained until mid-December.

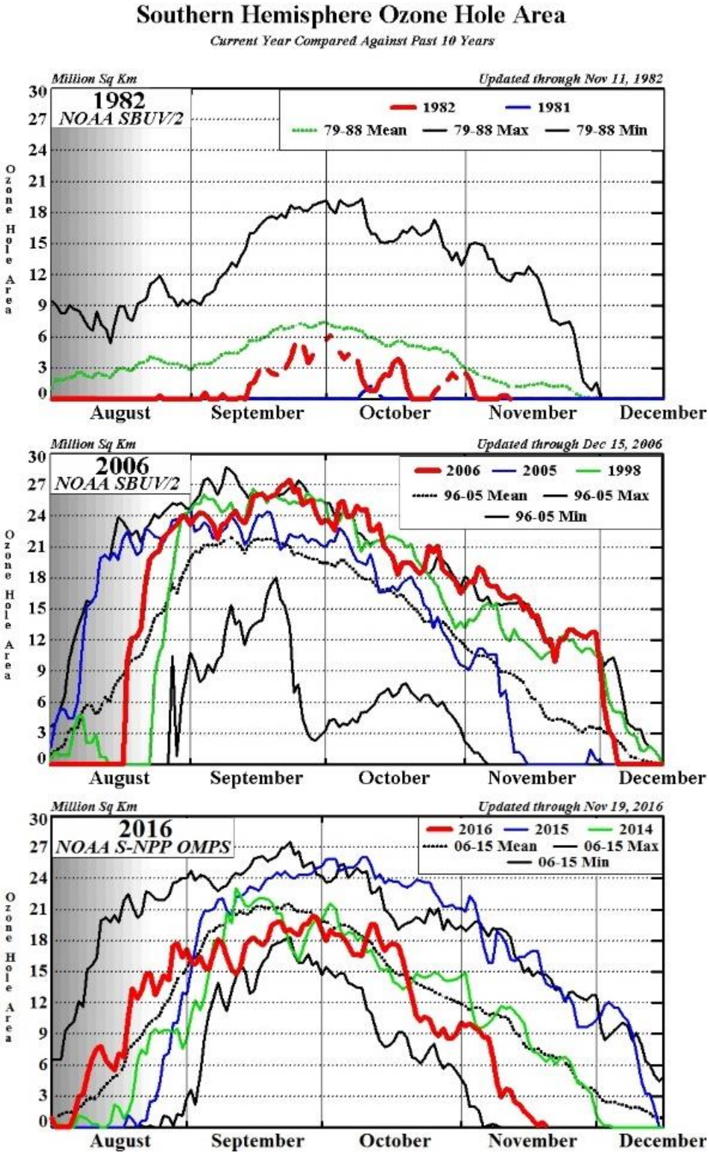

Fig. 5.29. Formation of ozone hole and changes in its extent (million km^2) in 1982, 2006 and 2016 in the southern hemisphere (Source: NOAA CPC[84]).

[84] Detailed figures about ozone-hole formation and the changes in its extent after 1980 can be found at:
http://www.cpc.ncep.noaa.gov/products/stratosphere/polar/polar.shtml and illustrative animations are available about the process for almost each year:
https://ozonewatch.gsfc.nasa.gov/ozone_maps/movies/

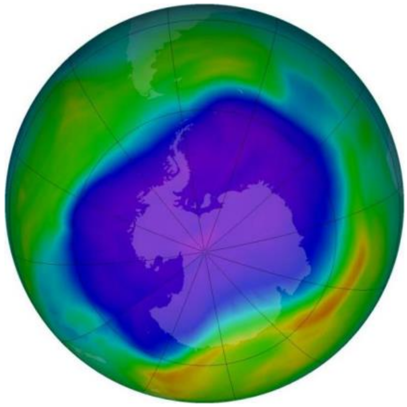

Fig. 5.30. Spatial extent of the largest ozone hole experienced so far: 24 September, 2006 (Source: *NASA Ozone Watch*[85])

The figures illustrate that the *ozone hole is not a permanent phenomenon, but has formed regularly above the Antarctic region every year for the last four decades*. Based on the statistical analysis of the past forty years, it seems that the final impacts of the ozone agreement (see Chapter 16.2.1) have been somewhat delayed, but the situation has not become worse in the Antarctic region since the second half of the 1990s; moreover, an upward trend is likely to occur.

Near the North Pole – as cooling is less than in Antarctica – PSCs can be observed for shorter periods. Although most of the ozone-depleting substances are released in the northern hemisphere, they are less able to bind in the stratosphere so they can travel to southern lands as well. This is the reason why 'ozone-hole-like' phenomena can also form periodically in the northern hemisphere; however, they are smaller than Antarctic ones in size, thinness and durability.

In the northern hemisphere, ozone depletion of more than 45% occurred during the very cold winter months of 1995-96, but more often in early spring (compared to the 1979-1986 average), but ozone content has not permanently dropped below 220 DU. However, for the first time on 30 November, 1999 an ozone hole with an estimated size of 1000x3000 km evolved above Northern Europe for only one day. In March 2011, a permanent ozone hole also developed in the northern hemisphere. While the ozone concentration was barely below 220 DU and its area extended to 1-2 million km^2, ozone depletion has exceeded 40% multiple times.[86] In February 2016, very cold weather was detected that was appropriate for

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[85] More detailed information is available at: http://www.theozonehole.com/ozonehole2006.htm

[86] Illustrative animations and several maps of the ozone hole in the Northern Hemisphere from 2011 can be found at: http://www.theozonehole.com/arctic2001loss.htm. This site will probably report about future phenomenon too.

PSC formation thus the development of an ozone hole was forecast, but one did not develop. There is also a significant ozone depletion in the northern hemisphere, but the ozone concentration has not reached the defined limits of 220 DU (thus, it is not defined as an ozone hole), although ozone holes may occur in the future in early springtime with an expected duration of few weeks.

The reason for the great difference between the ozone depletion in the Northern and southern hemispheres can be understood by studying three figures below. In the polar areas of the northern hemisphere the temperature in the winter time (half a year) is 10-25 °C higher than that of the Southern, and it falls below -78 °C only for shorter periods (and it does not drop below -87 °C). It was previously mentioned that these are the temperatures at which the formation of polar stratospheric clouds that accumulate ozone-depleting substances are expected (Fig. 5.31). The other reason is that, due to better atmospheric mixing, the general ozone concentration from which the depleting process starts is 100 DU higher in the northern hemisphere (Fig. 5.32). The consequences can be seen in the vertical distribution: while ozone is totally absent for up to a few weeks around the South Pole at an altitude of 15–20 km (where most of the ozone is located in the early spring period), only a significant decrease occurs in the northern hemisphere (Fig. 5.33).

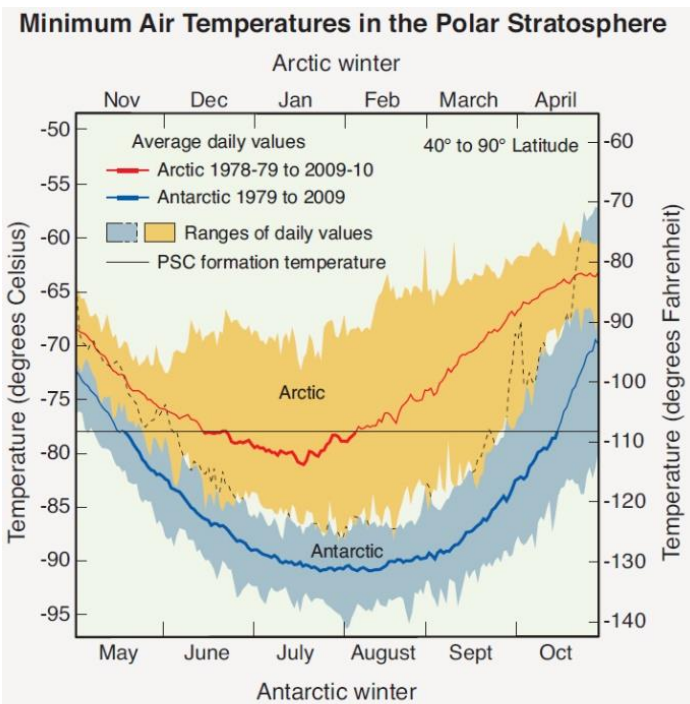

Fig. 5.31. Winter minimum air temperatures in the polar stratospheres of the northern and southern hemisphere (Source: Fahey and Hegglin 2010)

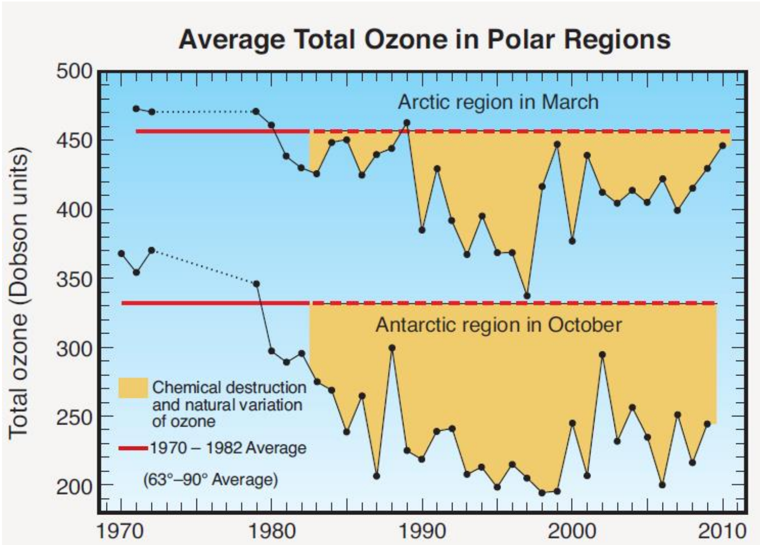

Fig. 5.32. Average total ozone in polar regions
(Source: Fahey and Hegglin 2010)

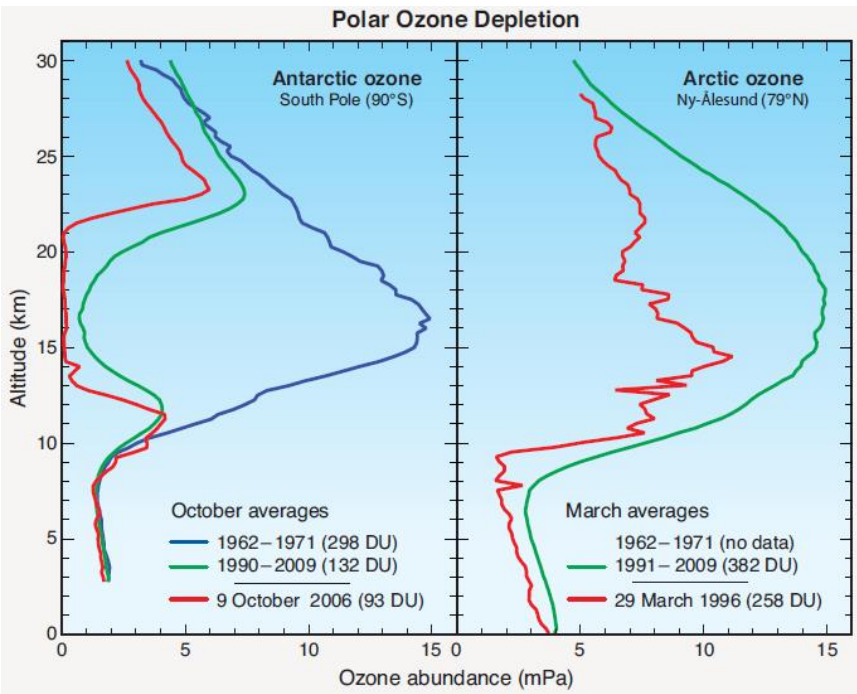

Fig. 5.33. Vertical differences in polar ozone depletion at two measurement stations located in the northern and southern hemispheres
(Source: Fahey and Hegglin 2010)

Ozone depletion poses a serious health risk. Looking at the potential areas of ozone depletion that threaten human health and the spatial distribution of the Earth's population, it can be concluded that although the most populated areas are not seriously endangered, six hundred million people are affected by increasing UV-B radiation due to ozone depletion, mostly in Europe (Fig. 5.34). Populations that live at a higher altitude can also be affected (for example, in the southern areas of Altiplano in South America).

Fig. 5.34. World population density (people/km^2)[87], and areas most affected by the harmful effects of ozone depletion on human health

5.3.3. Who is responsible for ozone-layer depletion?

It was discovered as early as the mid-1970s that some man-made compounds (gasses), while having no adverse effects under normal surface conditions, can be decomposed in the stratosphere – due to strong short-wave radiation – and can damage the ozone layer. This was confirmed by the discovery of the ozone hole in 1985. It was found that chlorine, fluorine and bromine compounds played a dominant role in ozone depletion. From the 1950s onwards, the spread of the freons (CFC-11, CFC-12) used in sprays, refrigerators, and air conditioners, and halons used in fire extinguishers and their release to the stratosphere caused ozone depletion. The Ozone-Depletion Potentials (ODP) of halons are multiples of the freons (Table 5.3).

[87] Source of base map: http://www.worldometers.info/world-population/#density

Table 5.3. Main characteristics of the most important substances that play a role in ozone depletion (Based on Fahey and Hegglin 2010)

Gas	Atmospheric Lifetime (years)	Global Emissions in 2008* (Kt/yr)	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
Chlorine gasses				
CFC-11	45	52–91	1	4750
CFC-12	100	41–99	0,82	10900
CFC-113	85	3–8	0,85	6130
Carbon tetrachloride (CCl_4)	26	40-80	0,82	1400
HCFCs	1–17	385–481	0,01–0,12	77–2220
Methyl chloroform (CH_3CCl_3)	5	Less than 10	0,16	146
Methyl chloride (CH_3Cl)	1	3600–4600	0,02	13
Bromine gasses				
Halon-1301	65	1–3	15,9	7140
Halon-1211	16	4–7	7,9	1890
Methyl bromide (CH_3Br)	0,8	110–150	0,66	5

* Includes both human activities (production, and banks) and natural sources.

Although the compounds responsible for the reduction of stratospheric ozone may be naturally produced in smaller proportions (Fig. 5.35), their industrial-scale utilization has caused serious changes. The international community reacted quickly to the perceived danger (Montreal Protocol – see later in Chapter 16.2.1), but due to the long residence time of these gasses the rapid decrease in emissions only very slowly made an impact. During the investigation of the greenhouse effect, it was found that freons (especially due to their large GWPs) also play a significant role in the global warming process, so their withdrawal from use is important in terms of both global atmospheric problems. In most cases, HFCs were introduced to replace freons. These gasses do not cause ozone depletion, but their spread has an increasing impact on the greenhouse effect (see Fig. 5.4 above).

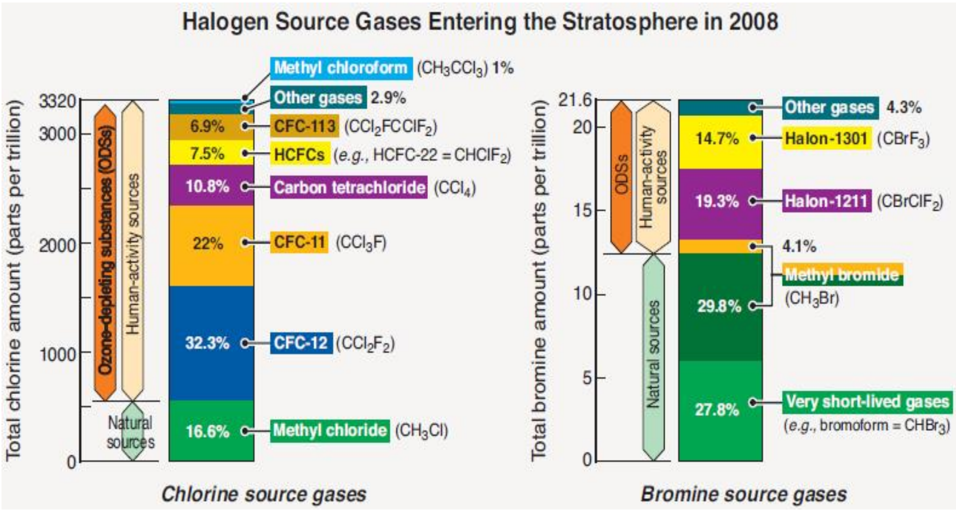

Fig. 5.35. Ozone-depleting gasses in 2018 (in: Fahey and Hegglin 2010)

Examining the issue of responsibility more specifically, it can generally be stated that among environmental policy principles, *a lack of precaution* is the guilty one. Humanity has used materials the environmental risks of which were not sufficiently known. However, once they were recognized, countries responded relatively quickly, depending on their economic capacity.[88] The largest users among developed countries (USA, EU, and Japan) used nearly 70% of all CFCs in 1986, which percentage dropped to 21% in 1995 and was below 4% in 2000. In contrast, use in China, considered a fast-growing but still 'developing' country in the 1990s, peaked in 1998 (35% of all use) and has since been reduced to a lesser extent (Fig. 5.36).

CFC production was eliminated by most developed countries in the mid-1990s, but China and India increased production in the 1990s. Production peaked only at the end of the decade and gradually declined after this, then ceased in 2009.

The worldwide use of halons was about one-fifth that of freons (two hundred and eighteen thousand tons) in 1986, which decreased significantly until 1994 (thirty-five thousand tons); after a rise in the production of China (in

[88] Detailed production and use datasets for countries are available through interactive query at: http://ozone.unep.org/en/data-reporting/data-centre

the mid-1990s) it increased until 1997 and then gradually declined. After 2004 it was low, and following 2009 it ceased. A review of the detailed data on the use of CFCs shows that the international agreement resulted in a rapid decline in the quantity being used, but the number of countries which used these substances decreased slowly at the beginning (1995: 173 countries, 2000: 158, 2005: 132, 2010: 8), and their use had only completely finished by 2016.

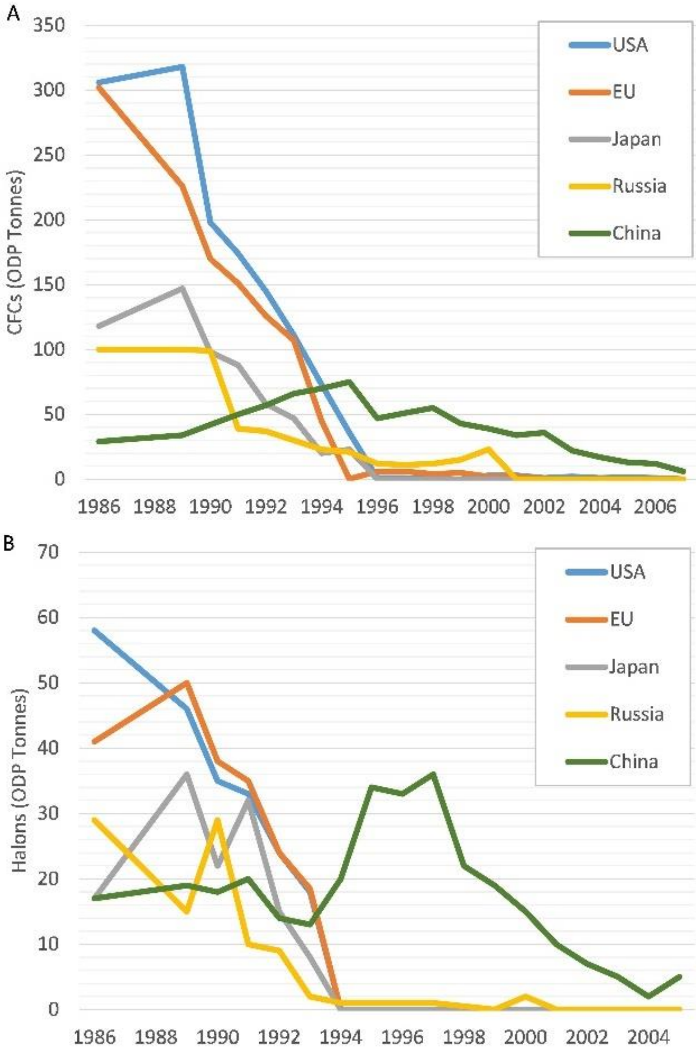

Fig. 5.36. Production of main ozone-depleting gasses 1986–2006 (Based on data from UNEP OS[89])

[89] Data are calculated for ozone-depleting potential (ODP), and amounts of less than one thousand tonnes were not considered.

Among the causes of ozone depletion, a natural factor, volcanic activity, may play an indirect role. For PSCs, the condensation core of ice crystals is mostly sulphur compounds and a large amount of sulphur is lofted into the air during larger volcanic eruptions. During the 1991 eruption of Pinatubo (Philippines), approximately twenty million tonnes of sulphur dioxide entered the stratosphere at up to 25 km and destroyed 10% of the ozone layer at medium latitudes. Such a large eruption may increase the frequency of PSC formation, thereby facilitating the accumulation of ozone-depleting gasses for 1-2 years, but its long-term impact is lower.

5.4. Acid rain

An important atmospheric environmental problem that affects huge areas is the deposition of acid, the better known term for which is *acid rain*. The phenomenon occurs in many parts of the world, although in many aspects it significantly differs from the global atmospheric problems that have been described so far. One difference is that it is not a unified global problem but a combination of regional problems over huge areas that does not affect the entire world, but primarily industrial and urban areas. The other difference is that the formation of acid rain is caused by gasses whose atmospheric residence time is shorter and limited to the lower atmosphere, the troposphere, which explains why the associated damage appears as a regional rather than a global problem.

In some industrialized areas, acidic air pollution was already being felt in the seventeenth century, and the damaging effects of sulphur compounds in the atmosphere were pointed out by R. A. Smith, an English chemist in the second half of the nineteenth century (he used the term 'acid rain' first in 1872). Later, in the early 1950s, researchers investigated the chemical properties of rainfall in the case of some extreme metropolitan air pollution; however, the problem of acid rain really emerged in the second half of the 1970s. The phenomenon has been often mentioned since 1978 and by the mid-1980s thousands of articles were dealing with this topic. But what do we mean by *acid rain*?

The pH of normal precipitation varies between 5 and 6.5, therefore rain which has a pH of less than 5 is considered acid rain. The gasses (sulphur, nitrogen and carbon oxides) that result in the acidification of rain enter the atmosphere mainly due to fossil fuel combustion and industrial activities. These gasses can form sulphuric acid or nitric acid with the water vapour in the clouds, thus they alter the alkalinity of precipitation. Initially, the appearance of acid rain (and, for example, the resulting forest degradation) was thought to be a natural phenomenon, although later more detailed studies revealed its true nature (sulphur emitted by volcanoes can naturally cause acid rain).

Globally, sulphur is considered responsible for 60 to 70% of all acid rain – and nine-tenths of this is due to human activities. Coal generally has a sulphur content of 2-3%, which, when burned, is released into the air as SO_2. The second most important source of sulphur is metallurgy, while the third – a natural pollutant – is volcanism and the decomposition of organic matter. As for the nitrogen oxides required for the formation of nitric acid, human activities are 95% responsible. The most significant sources of NOx are carbon, petroleum and natural gas (combustion, transport, and the chemical industry), fertilization, soil bacteria and wildfires.

The above-mentioned main sources of pollutants show why industrial and metropolitan areas are those most affected by acid rain. In extreme cases, the pH can even drop to 2-2.5 (in industrial, metropolitan environments it can often fall below a pH of 4). The areas that are affected depend on the main wind directions. Sulphur dioxides cause significant effects at distances of 1500-3000 km, while damage from nitrogen oxides may occur at even longer distances. This is the reason why it is mostly British, German and Polish pollution that is responsible for the acid rain in Scandinavian countries (Fig. 5.37) and about one-third of sulphur pollution in Japan comes from China. The acidity also depends on meteorological conditions besides the substances in the atmosphere. Since the amount of dissolved substances in rain depends on the size, lifespan and temperature of rain drops, it is generally observed that clouds are more acidic than rain, rain is more acidic than snow (as ice can not absorb more gas), and a summer thunderstorm is more acidic than a light rain. Acids that accumulate in snow, however, may have 5-10 times as much impact as acid rain during spring melting for a shorter period of time .

A widespread but less discussed type of acid deposition is so-called *dry deposition*. In this case, acidic anhydrides in the dry atmosphere cannot form acids but are deposited and later, when exposed to moisture, exert their acidic effect. In the summer of 2001, the author of this book had an astonishing 'meeting' with this phenomenon. Half a day after arriving in Mexico City, I found that my nose was bloody, and my travelling companions experienced the same. At this point I realized that this was the result of dry deposition. In the very polluted metropolis (in the dry season, when significant amounts of smog evolve), acid anhydrides float in the air until they make contact with moisture in the mucous membranes of our noses and form acids. Our problem disappeared after leaving Mexico City, but the unpleasant feeling still remained that those who live there (under similar circumstances) are exposed to this phenomenon repeatedly. And this is just one of the diverse consequences of acidic deposition. A few years later, I went to Beijing, which is also characterised by smog. Because of my prior unpleasant experience, I checked how my nose responded to the smoggy conditions. Due to the higher levels of humidity, I felt no adverse changes (due to this experience I realised that there was no similar physiological effect to that of Mexico City, even in the dry season, because the mineral composition of the dust from the Inner Asian loess areas decreases the effect of sulphuric acid in the atmosphere).

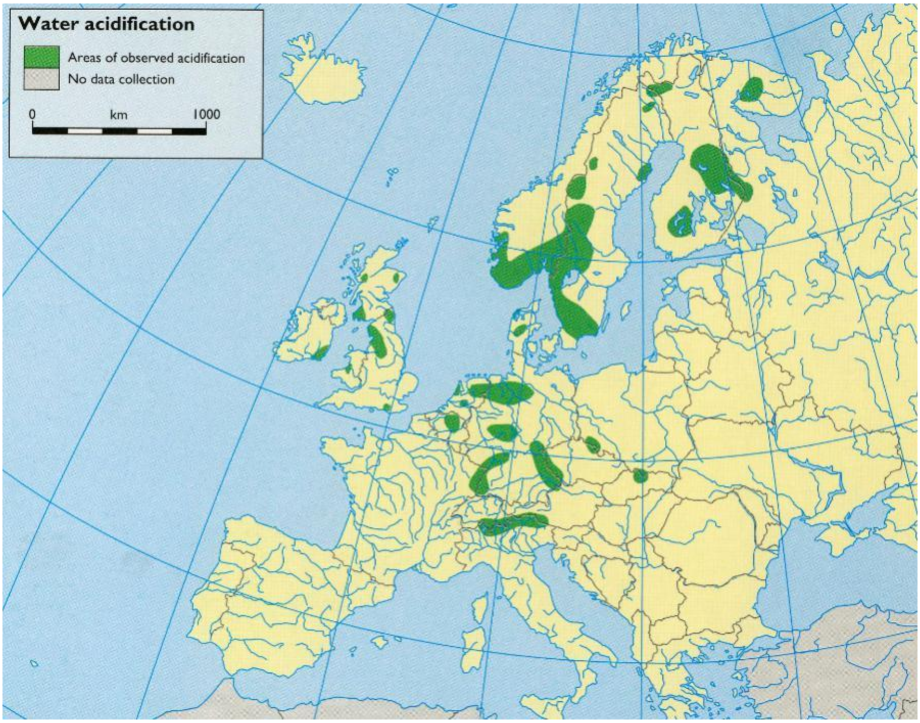

Fig. 5.37. Water acidification in Europe at the end of the 1980s
(Source: Europe's Environment 1995)

Research into acid rain has revealed that (besides carbon dioxide) it is mainly sulphur and nitrogen oxides that are responsible for acidity, but there may be further compounds depending on the local conditions. Some types of carbon may contain chlorine from which hydrochloric acid can form; in intensive livestock farming ammonia can be released from manure which later turns into nitrogen oxides; furthermore, during industrial or transportation activities volatile organic compounds can be released. In many cases, damage to trees is caused by the ozone generated in photochemical smog (according to some estimates, at least 25% of the leaves of a quarter of Europe's tree stock were lost in this way).

Acid rain can have direct and indirect effects. Direct impacts include, e.g., damage to plants and structures due to the acid rain (or dry deposition). Large forest areas may suffer damage or die, and elements of built infrastructure (or decorations) can be destroyed. In Mexico it was found that up to 1 mm of material can disappear from the surface of some Mayan ruins every 12 years. Acid rain can change the pH of surface waters to such an extent that some wildlife is killed off. From the 300,000 Canadian lakes, more than approximately 14,000 experienced such water quality changes due to acid rain that their fish stocks changed significantly. An extreme example is Clearwater Lake, where due to the Sudbury metallurgy units the pH of the lake water decreased to 4.1 (even after environmental interventions in 1986, its pH was only 4.7). At the beginning of the 1990s, 14,000 of the 85,000 lakes of more than one hectare of water surface were suffering from significant acidification, and in the case of more than 4,000 lakes, the process was in its initial phase. As a result, about 40% of the surface waters in the country lack acid-sensitive species.

Interestingly, wildlife can be damaged not only through destruction, but also through 'overnutrition' induced by the process. Nitrates in the atmosphere can accelerate the growth of some plants to such an extent that they become less resistant. It has been observed that due to such 'overnutrition' some species develop much more rapidly and suppress others in their environment, and areas of low diversity can form.

The most significant damage caused by acid rain is damage to soil. When soil pH decreases, calcium and magnesium salts, important for plant development, are mobilised first, but a further decrease in pH can also lead to the mobilisation of life-threatening ions such as aluminium or cadmium. Along with the pH change, soil bacteria and earthworms are destroyed, the biological activity of soils decreases, organic matter degradation decelerates, while significant nutrients are removed from the natural cycle. It is a serious problem that the process can remain hidden for a long time, and only small signs of it can be perceived.

A forest may remain green, but its rate of growth decrease, or there may a change to species less sensitive to pH, thus a slow change in species composition occurs. Some examples of this are the following: In the Appalachian Mountains (USA), the death rate of oak trees doubled between 1960 and 1990. In Germany, mainly pine trees, and in Hungary, deciduous forests, suffered major damage in the 1980s. In eastern Canada, more than half of all forests have been damaged by acid rain and their declining vitality can be observed in many areas; four-fifths of the country's population live in areas where rain is particularly acidic. It has been noted that, besides the direct effects of acid rain, several indirect effects (a decrease in soil pH, nitrogen accumulation) or extreme weather conditions, pathogens and pests can contribute to forest degradation.

The significance of pollution-causing acid rain is mostly due to three factors: *industrialization, deficiencies in environmental regulations, and gas emissions associated with volcanic eruptions.* Developed, but not environmentally aware industry severely contaminated Europe and North America until the 1980s, and it was here that the serious consequences of the problem were faced for the first time.

Anthropogenic emissions of SO_2 increased rapidly after World War II (1950: sixty-three million tons, 1970: one hundred and forty million tons) and reached a maximum in 1980 at one hundred and fifty-one million tonnes. The later decline is due to the fact that it was confirmed in the late 1970s that acid rain was contributing to the formation of many environmental problems. As a consequence of the measures that were taken, the largest polluter, Europe, reduced its SO_2 emissions by more than half over twenty years (1980: seventy-one million tonnes, 2000: twenty-seven million tons). However, Asian countries have experienced a steady rise (related to increasing energy consumption) due to their delayed economic development (Fig. 5.38). Thus, as a result of the more effective environmental protection of the more developed countries, the problem is now mostly affecting rapidly industrialising developing countries (and their environments).

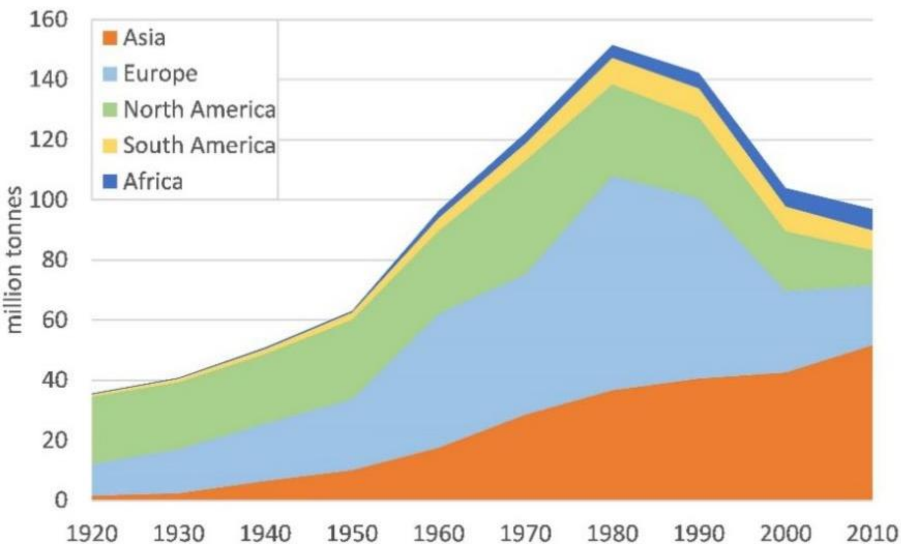

Fig. 5.38. SO_2 emissions by continent (1920–2010) (million t SO_2)
(Data source: Our World in Data)

The emission trends of specific countries are very different (Fig. 5.39). The United States, being previously the largest emitter, started reducing its emissions in the mid-1970s and since the early 2000s has also accelerated the rate of decline (thus, overall, emissions have dropped to less than one-tenth of the former level). Germany, after the reunification of the country, mainly abolished the most environmentally damaging sectors that were characteristic mostly of the eastern regions. In Japan, the fast-growing emissions of the 1960s were followed by a similarly rapid decline in the 1970s. Concerning the two big Asian countries over the last few years, the emissions of China, the largest SO_2 emitter, have been spectacularly decreasing, but unfortunately those of India have grown considerably, mainly in the eastern regions.[90]

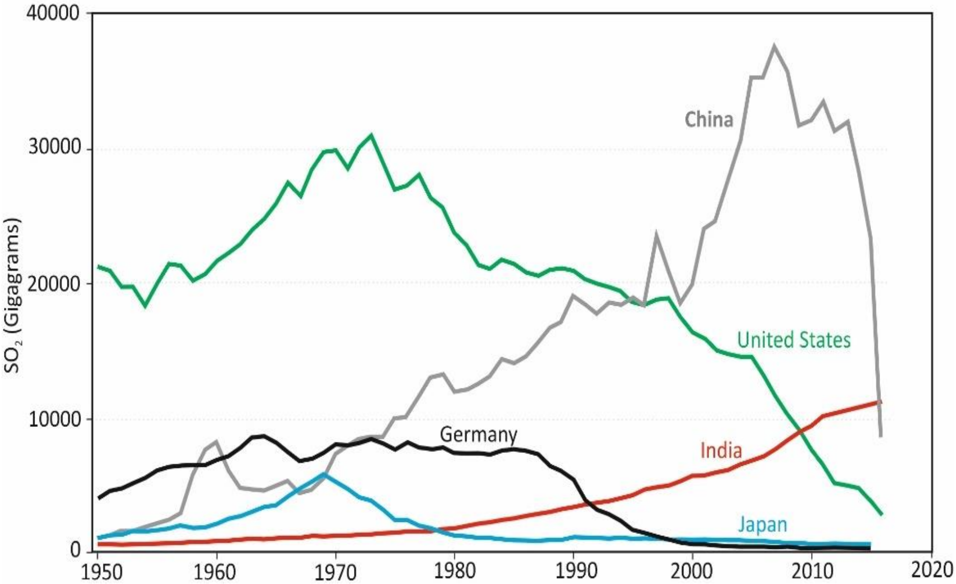

Fig. 5.39. SO_2 emission trends of the major emitting countries[91]

Comparison of anthropogenic and volcanic-related SO_2 emissions (Fig. 5.40) shows that volcanic emissions are not significant (usually 1-2 million tonnes per year). Although significant volcanic eruptions (occurring every several decades) can temporarily affect the sulphur content of the atmosphere (as mentioned earlier, the Pinatubo volcano during the 1991 eruption emitted approximately twenty million tonnes of SO_2 into the atmosphere, corresponding to one-seventh of annual anthropogenic emissions at that time), human influence dominates overall.

[90] Illustrative figures can be found here: https://www.nasa.gov/feature/goddard/2017/chinas-sulfur-dioxide-emissions-drop-indias-grow-over-last-decade

[91] The individual figures can be found here: https://chemistry.beloit.edu/Rain/pages/links.html

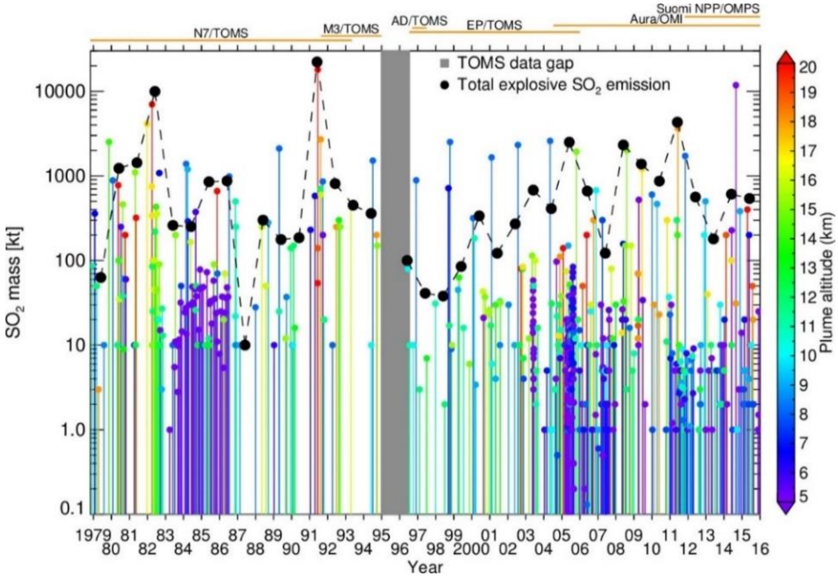

Fig. 5.40. Estimated SO_2 emissions from volcanism (1979–2016) (Carn 2015[92])

5.5. Air pollution

Nowadays, increasing focus is paid to air pollution among global environmental problems. According to WHO data, 92% of the world's population was exposed to unsafe levels of air pollution and an estimated three million deaths a year are linked to outdoor air pollution and 4.3 million to indoor air pollution. The numbers are double this in terms of direct and indirect deaths due to smoking (6.3 and 0.9 million) as the result of the self-destructive activity of humans. Air pollutants may enter the atmosphere naturally, or through human activity. Since people inhale the air that is directly available in their surroundings (except for some exceptional cases), its quality is always important.

5.5.1. Air pollution of natural origin

The best-known form of air pollution is perhaps dust, which occurs mainly in dry desert and semi-desert areas for natural reasons, but can also be released during volcanic eruptions. Another natural component of the atmosphere is CO_2, which does not cause health problems at its current mean concentration (0.04%), although it can accumulate in closed spaces, and even a doubling of the normal concentration can cause fatigue and reduce performance (at above 5%

[92] The figure can be found at:
https://disc.gsfc.nasa.gov/datasets/MSVOLSO2L4_V2/summary

it can cause death). High CO_2 concentrations under natural conditions can also occur in relation to volcanic activity. One of the deadliest catastrophes of this type occurred near Lake Nyos, resulting in the death of 1746 people in 1986.[93]

Among natural factors, volcanic activity also accounts for the emission of a significant amount of sulphur into the atmosphere, and does not require any spectacular explosive volcanic activity. If you have been near any active volcanic areas you may have noticed that many years after the spectacular phase of volcanic activity sulphur vapour is still being emitted in several places. Most sulphur dioxide is released into the atmosphere as a result of volcanic eruptions. Its impact through atmospheric aerosols can be significant for the global energy balance and the amount of stratospheric ozone.

It is less well known that the radioactive content of certain natural rocks can be a form of dangerous air pollution. According to a study from the US, radon accumulating in closed spaces is the second most significant cause of lung cancer deaths after smoking (accounting for approximately one in every eight people with lung cancer, which means 21,000 deaths per year can be attributed to this).

5.5.2. Some health consequences of anthropogenic air pollution

Near-surface ozone is a highly toxic, aggressive gas and the main component of photochemical smog (or Los Angeles-type smog). Due to dry air and strong sunlight, firstly ozone, and then reactive organic radicals and finally peroxyacetyl nitrates (PANs) can form in urban air through the decomposition of nitrogen oxides, carbon monoxide (CO), and various hydrocarbons emitted mainly from cars. Photochemical smog strongly irritates the mucous membrane, and ozone damages plant leaves.

Volatile organic compounds (VOC) can easily become gasses under normal conditions and are therefore used as solvents in a variety of industrial and household chemicals, paints, waxes and lacquers. They play a role in the generation of near-surface ozone and the development of urban smog.

Although the production and utilization of CFCs has effectively been reduced around the world for 20-30 years, old refrigerators and air conditioners will be a major source of these harmful substances for a long time. (Due to the delayed process of industrialization in China and India, as well as the later production and use of these substances, it will mainly be a problem for these countries in the long term).

Lead and certain heavy metals released into the air mainly by traffic can also cause health problems. The transition to unleaded petrol in the 1980s greatly improved air quality.

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[93] Numerous articles and videos are available about the background to the catastrophe on the internet.

A separate group of air pollutants is particulate matter less than 10 µm (PM_{10}) in size. Most of these pollutants are solid and can enter the respiratory tract due to their size. For a long time, this size range of particles was studied, but later it was found that 'fine' dust particles with a diameter smaller than 2.5 micrometers ($PM_{2.5}$) pose a greater risk because after inhalation they can enter the lungs, be absorbed and circulate in the blood system. $PM_{2.5}$ particles consist of secondary aerosols, combustion products and condensed organic or metallic particles that contribute to mutagenic activity and acidity, and can cause respiratory and cardiovascular diseases. In urban environments, their amount is increasing considerably and has serious health consequences, leading to a decline in average age.

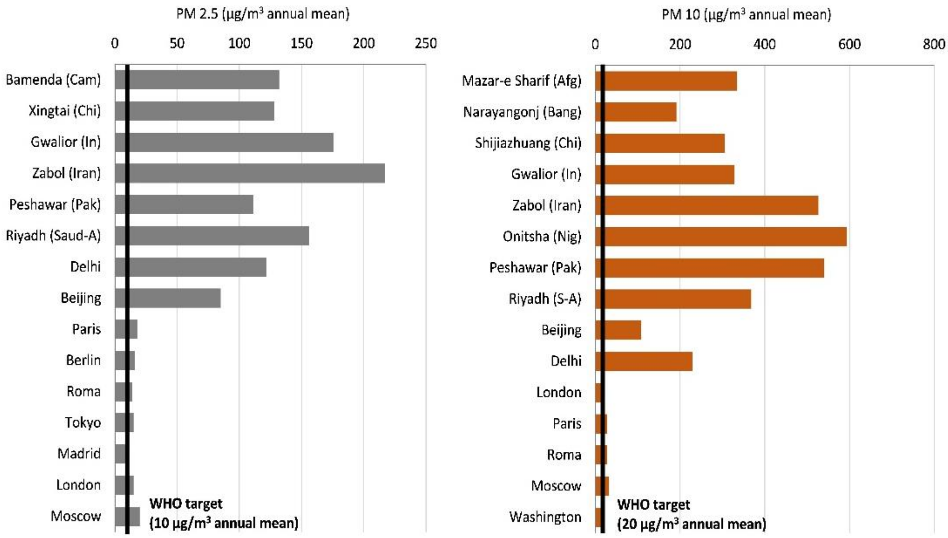

Fig. 5.41. Annual mean particular matter content (µg/m^3) in cities with high air pollution and in some capitals at the beginning of the 2010s (based on WMO data)

The air pollution in large cities is mostly caused by industry and motorization combined with a lack of (or not strict enough) environmental standards. A photo from a publication mentioned in the Introduction to this book astonished me: it illustrated how a blue sky could be seen in Beijing during times of smog (on a huge LCD screen). In the summer of 2006 from my room on the 7th floor I was surprised to realise that I could not figure out what time it was in the morning: if it were cloudy, or just urban smog. In China, the situation has improved considerably in recent years, and the cities of Asia and Africa are experiencing a much worse situation than the Chinese capital (Fig. 5.41). In these countries, central governments which mostly want to improve the environment are still powerless against local governments (which foster rapid economic development), industrial lobbies and motorisation: the phenomena of a consumer society.

According to the overview of detailed air pollution data for big cities,[94] it can be stated that the most polluted cities can be found in Asia and Africa. PM_{10} concentration exceeded 200 µg/m^3 in the case of twenty-seven cities out of thirty-one in Asia (eleven in India) and four in Africa (all in Nigeria). In terms of air pollution data for cities, the number of cities exceeding 100 µg/m^3 was fifty-four out of one hundred and twenty-two India, forty-nine out of two hundred and ten in China, and the situation is also bad in Pakistan (5/5), Bangladesh (7/8), Saudi Arabia 7/7), Kuwait (10/11), Iran (12/25). $PM_{2.5}$ concentrations exceeded 100 µg/m^3 in the case of thirty-two cities out of thirty-four in Asia (eighteen in India, six in China) and two in Africa. However, based on satellite image analysis, it is clear that not only is the air very polluted in the cities, but also in the surrounding environment (Fig. 5.42).

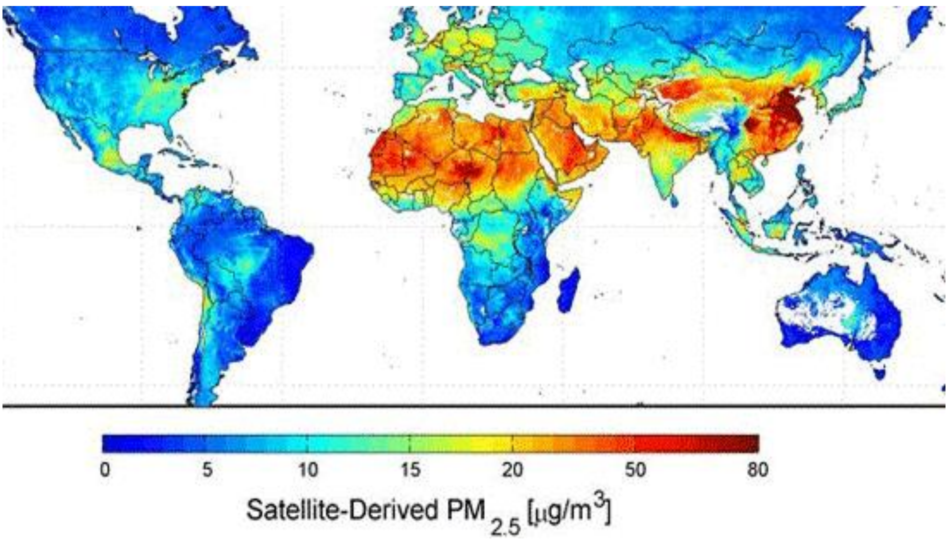

Fig. 5.42. Global satellite-derived map of $PM_{2.5}$ averaged over 2001–2006 (Author: A. v. Donkelaar)[95]

The situation is much better in Europe, but there is still work to do. If not the annual datasets, but the most polluted periods are analysed, air quality in Eastern Europe can be evaluated as unfavourable (Fig. 5.43).

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[94] Current data for 2971 cities across the world for the period 2013–2014 can be found in the WHO database available at: http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ under the menu *Ambient (outdoor) air pollution database*.

[95] The figure is available at: https://www.nasa.gov/topics/earth/features/health-sapping.html

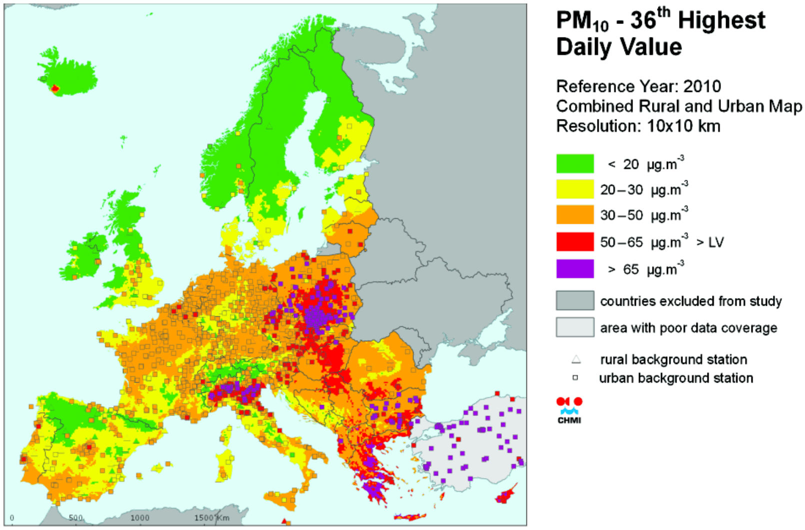

Fig. 5.43. Air pollution in Europe in 2010 (Source: EEA[96])

5.5.3. Indoor air pollution

There has been no comprehensive study of indoor air pollution for a long time, since it has proven difficult to extend the few data that existed across space. However, it is known that conventional combustion techniques in closed spaces release a lot of harmful substances into the air in some places – often those with minimal ventilation. Many think – especially those who live in a city with bad air quality – that the air outside of their homes is more polluted, but in fact this air is constantly moving and mixing, and sometimes its pollutant contamination is diluted. Indoors, however, pollutants constantly accumulate (without ventilation), and people can get used to this. Although the share of solid fuels used indoors is steadily decreasing, it is still significant in poorer African and Asian countries (up to 40–70%[97]). The most commonly used fuels are wood, charcoal, and coal (mainly in China), but the incineration of dried cow manure is also common, mainly in South Asia (in India, approximately 10%).

Many other pollutants can cause problems indoors: a wide variety of chemicals, carbon monoxide from heating, bacteria that live in air conditioners, etc. Significant indoor-air-related mortality is estimated due to these issues (2.6 million people in 2016: 1.9 million people in Asia and 550,000 people in Sub-Saharan areas).

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[96] The figure is available at: https://www.eea.europa.eu/data-and-maps/figures/pm10-36th-highest-daily-value-2010

[97] Interactive maps illustrating the changes can be found at: https://ourworldindata.org/indoor-air-pollution

6. Global water problems

According to current scientific knowledge, water is essential for life: it has played an important role in the development of wildlife and is a major factor in the metabolic processes of certain organisms. Therefore, anyone who seeks to find life outside Earth mainly begins with research into the existence of atmosphere and water. Water is not only an important part of nature, but plays a major role in the processes that take place in the abiotic environment too. It influences mineral and rock formation, it plays an important role in material circulation on Earth's surface and climate formation, and it is also essential for economic activities. It appears to be available in large quantities (about 70.9% of the Earth's surface is covered with water), but it is one of the most endangered elements on Earth due to the unequal distribution of freshwater resources, contamination, and other environmental issues that are described later.

The total volume of water on Earth is about 1.4 billion km^3, the dominant share (97.5%) being the salt water in the oceans and seas. From all freshwater resources (2.5% of the total volume), a substantial amount (68.7%) is in the form of ice (polar ice caps, glaciers, constant snow cover); the shares of groundwater, constantly frozen areas, and atmospheric and surface water resources (including the water in living organisms) are 30.1%, 0.8% and 0.4%, respectively. Only slightly more than half-a-million km^3 is involved in the water cycle annually, although smaller territorial and temporal changes have a significant impact on human life. A delayed monsoon or a flood due to very heavy rains can threaten the lives of hundreds of thousands of people (through hunger and flooding).

Over large parts of Earth the existence of water has been considered permanent for a long time, and it was only realized in the last few decades that the availability of water resources is limited. Oceans and seas were also considered an unlimited food source, but it became clear in the 1990s that sea fishing could not be substantially increased. We have not taken care to protect water for a long time, as a result of which most surface water can now only be directly consumed at serious risk to health, and the world's seas have become the main recipient of anthropogenic pollution. The result: the rapidly increasing population and the irresponsible use of the environment have set a limit on the use of one of the most important conditions for life. Freshwater has now become a resource of strategic importance. Therefore, more attention needs to be paid to the (mostly) clean water that is involved in the water cycle.

Several calculations have been made over the past decades to estimate the annual volumes of evaporation and precipitation in the water cycle, which resulted in estimates of approximately 510–550,000 km^3. This can be considered the renewable water resource, although nearly four-fifths of this water does not reach the continents, thus it is basically not available to humans; moreover, a significant part of all precipitation evaporates from land, further reducing available resources. A recent assessment – using remote-sensing data and mixed-methods models, besides surface data – resulted in a figure of 520,000 km^3 for evaporation (449,500 km^3 from the world's seas and 70,600 km^3 from land) (Fig. 6.1).

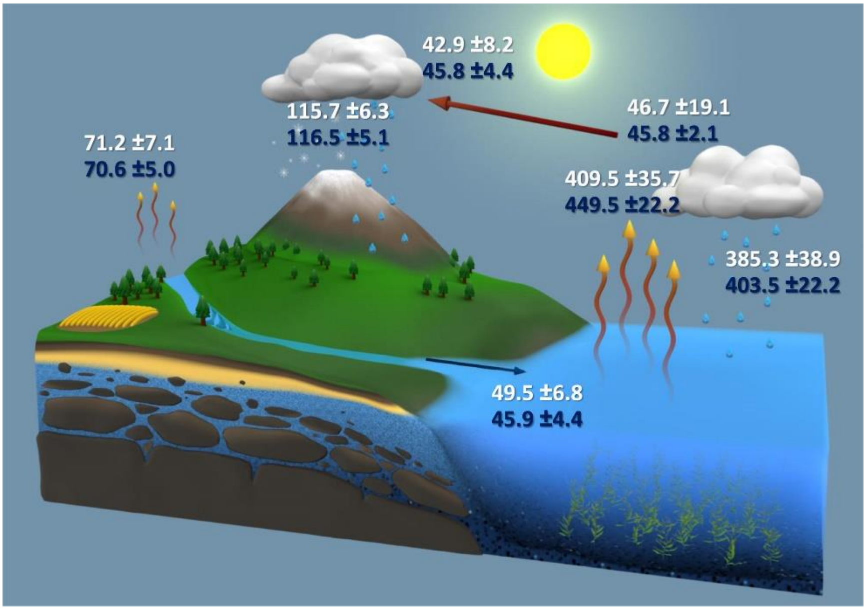

Fig. 6.1. The global water cycle in the first decade of the twenty-first century (thousand km^3) (Source: Rodell et al., 2015[98])

Note: White numbers are based on observational products and data-integrating models. Blue numbers are estimates that have been optimized by forcing water and energy budget closure, taking into account uncertainty in the original estimates.

According to these estimates, 403,500 km^3 of precipitation falls back into the oceans (approximately 5% more than previously calculated). The volume of water[99] that evaporates from land is the same as that found in previous calculations, but the volume of precipitation is somewhat higher (116,000 km^3 compared to the formerly estimated 110,000 km^3). Forty-six

[98] The figure and its theoretical background can be found at: https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-14-00555.1

[99] From the approximately seventy-one thousand km^3 of water that evaporates from land, approximately twenty-one thousand km^3 is due to transpiration of vegetation while fifty thousand km^3 involves evaporation from land.

thousand km^3 of water returns to the world's seas from the land in the annual water cycle, thus, *the latter volume is the renewable water resource available to humanity.*

The above-mentioned facts need to be supplemented. Most of the water that returns to the sea flows through rivers, but some infiltrates into the soil and flows underground, reaching the sea only after a longer time. Humanity also uses subsurface water resources too. However, if this water use is larger than the groundwater flow, previously stored, so-called fossil water resources have to be used. As a consequence of climate change, 500-600 km^3 more ice and snow melt than accumulate, but this happens mostly in places where the water is not available to humanity, as it directly enters the sea (e.g. in Antarctica and Greenland).

6.1. Problems with freshwater

6.1.1. Resources and use

Renewable water resources available for human use are very unequally distributed on Earth. According to the FAO annual report from 2015, 42.8 thousand km^3 of precipitation falls directly on land (excluding Antarctica), 45.6% of which is over America, and from this amount nearly two-thirds over South America (Fig. 6.2). The greatest extremes are experienced in Africa, where only 1.2% of rainfall on the continent falls over North Africa. In Asia, the share of Central Asia and the Middle East is very low (2% and 4.1%).

The growing population, its food supply and urbanization have caused rapid growth in water use (Fig.6.3). Growth was especially fast in the 1960s and 1970s, and has now exceeded 4000 km^3. The large differences in the use of this natural resource[100] and between populations means that the renewable water resource per capita is about 30,000 m^3 in South America and Oceania, while in large areas of Asia it is between 1,100 and 2400 m^3, but it is only around 250 m^3 in North Africa (the world average had decreased from 14,000 m^3 at the beginning of 1960s to less than 5,900 m^3 by 2014). Less water resources and the growing population in many countries cause water scarcity or water stress.[101] In 2015, about two-thirds of people suffered from water stress, and 1.8 billion people lived in areas of water scarcity (Fig. 6.4). These background conditions basically determine the everyday lives of the population in the given areas.

[100] Climate change may influence the amount of water resources in the future.

[101] A country is considered to be in a position of water scarcity if renewable water resources per capita are less than 500 m^3; countries are defined as water stressed is if this value is less than 1000 m^3. Available water resources can further be decreased by quality problems, if they hamper water use.

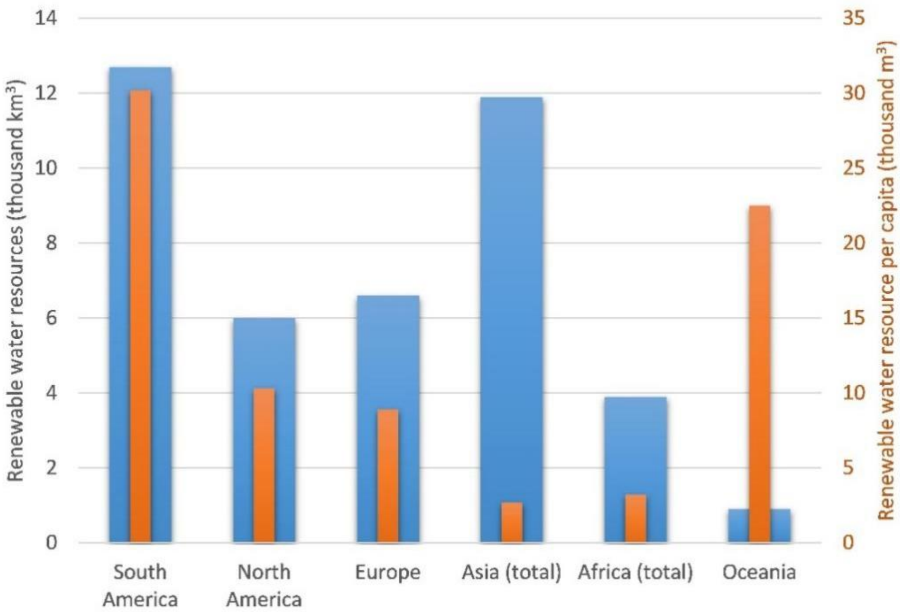

Fig. 6.2. Annual renewable water resources on the continents (thousand km^3) and renewable water resources per capita (thousand m^3) (2018)
(Data source: FAO AQUASTAT and Worldometers)

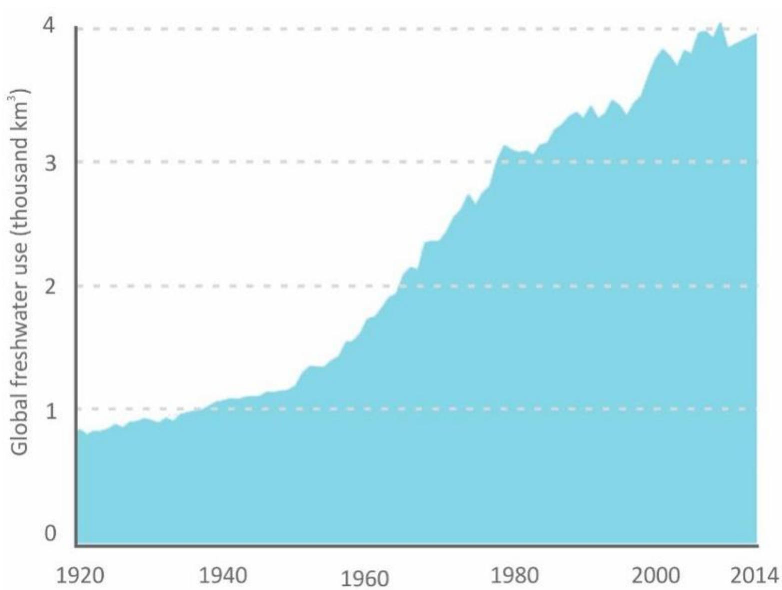

Fig. 6.3. Global freshwater use (1920–2014) (thousand km^3)
(Based on IGBP data)

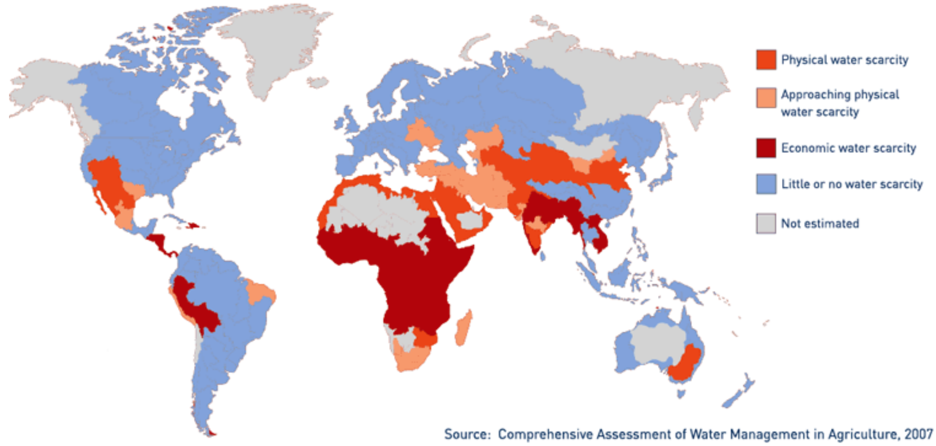

Fig. 6.4. Physical and Economic water scarcity on Earth (Source: Comprehensive Assessment of Water Management in Agriculture[102])

Water problems became increasingly serious following the 1960s. The 1980s were declared by the UN to be the *International Drinking Water Supply and Sanitation Decade* – this confirmed that the situation had became a global problem. Later, it was the main topic of a UN conference (Dublin, 1992), while it has become increasingly apparent that, besides food, water is another 'bottleneck' for humans in the future, and nowadays the importance of water has already preceded that of food.

The water problem, both in quantitative and qualitative terms, is becoming increasingly serious. Water use is rising everywhere in the world. At the beginning of the third millennium, humanity used about 54% of all available freshwater, and this figure is expected to increase to 70% by 2025.

Water quantity problems, as described earlier, are aggravated by quality problems (this can be confirmed by maps[103]) and the affected populations have the same numbers. According to a WHO report from 2015, around 2.4 billion people are risking their health due to poor water quality[104] (665 million people

[102] The term *physical water scarcity* is used to define an area in which industry and agriculture use more than 75% of surface water flows*; approaching physical water scarcity* means water use of over 60%; *economic water scarcity* is when social or financial factors hinder water use; *little or no water scarcity* areas are defined as being where less than 25% of the surface water flows are used.

[103] Detailed information and interactive maps demonstrating spatiotemporal changes can be found at: https://ourworldindata.org/water-access-resources-sanitation

[104] It is favourable that this number has halved in a quarter of a century (1.26 billion people in 1990). It is unfavourable, however, that half of the population that suffer water shortages live in the Sub-Saharan region (326 thousand people).

due to a lack of healthy drinking water, 1.8 billion people due to a lack of adequate water quality/or reliable access to water of good enough quality to be safe for human consumption). In the past few decades, the number of affected people has decreased, but in 2016, 1.7 million people (including 446,000 children under the age of five) died of diarrhea- and water-related infections (the latter number is many times more than deaths caused by wars). In countries with large populations, like China, India or Indonesia, twice as many people die of dysentery as die of AIDS.

Given the problem of access to healthy drinking water, the Johannesburg Conference (2002) defined this as one of its main goals, and the UN declared 2003 as the *International Year of Freshwater*. Later, this was also among the global goals of the world organization (Sustainable Development Goals, 2015).

Growing water use nowadays exceeds the rate of population growth (between 1950 and 2014, population increased by 2.87 times, and water consumption increased by 3.25 times). During the twentieth century, agricultural, urban and industrial water use grew by 5, 19, and 25 times, respectively. However, there are huge territorial differences not only in water resources but also in terms of water consumption. The three top water users (in 2014, India with 761 km^3, China with 608 km^3, and the USA with 486 km^3) account for about 48% of the world's consumption.

Concerning economic sectors, *the largest water user is agriculture*, followed by industry and communal use (including drinking water use). Problems related to hunger in the 1950s could only be solved by using a significant amount of fertilizers and chemicals, along with irrigation to ensure safe production. As a result, the share of agriculture in global water withdrawals is 70%, and is below 50% only in Europe and North America, but exceeds 90% in South Asia (Fig. 6.5); moreover, it is more than 98% in Afghanistan. The huge increase in agricultural water withdrawal has resulted in several adverse environmental impacts, and humanity is approaching the limit of long-term sustainable water use, mainly due to these agricultural needs. This is indicated by the fact that since 2001 global water use has not substantially increased (see Fig 6.3). Four countries stand out considering their use of water in agriculture (India, China, the USA, and Pakistan).

As mentioned before, due to water withdrawals the discharge of many rivers has decreased significantly (and their surrounding environment lacks water too), and contamination that enters watercourses under low water conditions results in a higher concentration of pollutants and thus increases health risks and management costs. Such changes are major limiting factors in water use, even without the effects of climate change.

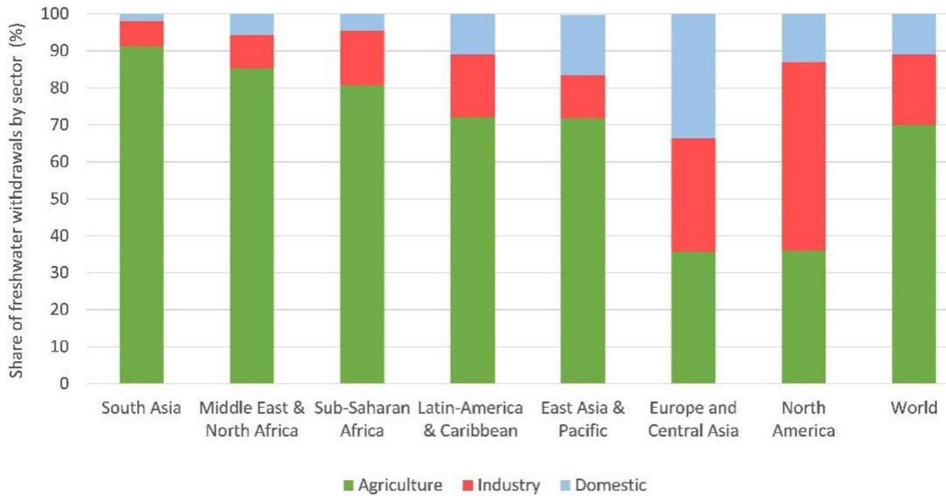

Fig. 6.5. Agricultural, industrial and municipal water withdrawals according to continents in 2014 (Source: based on FAO AQUASTAT data)

Water use will still grow in the future. The bottlenecks of available water resources are being 'solved' by the extraction of groundwater in many places. In 2010, around 220 km^3 of groundwater was extracted throughout the world. The areas with the largest groundwater use are the USA, China, India, North Africa and the Arabian Peninsula. According to estimates, agriculture uses at least 125-150 km^3 of non-renewable (or very slowly rechargeable) groundwater annually, causing further environmental problems. According to an OECD study from 2015,[105] the largest user of groundwater for agricultural purposes is the USA (68 km^3).

The most irrational water use has occurred in Saudi Arabia where three-quarters of the country's water use was fossil water, exploited with state aid, which was used for such a large volume of cereal production in a desert, semi-arid environment[106] (increasing the size of farmland by twenty times) that by 1984 the country had become self-supporting and later a significant *cereal exporter* (!). By the end of the 1990s, however, it had become clear that this method could not be sustained permanently without the depletion of water resources in the foreseeable future, which led to a decline in state aid and, consequently, production. In order to replace groundwater resources, dams were constructed for the retention of temporary waters, treated sewage water was used for agricultural purposes, and water-desalination plants were built to use sea water.

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[105] https://read.oecd-ilibrary.org/agriculture-and-food/drying-wells-rising-stakes_9789264238701-en#page22

[106] See later, Figure 11.3

Realizing the unsustainability of large-scale agriculture in desert areas, the country has also been ranked as the world's largest buyer of agricultural land.

The over-exploitation of groundwater also causes problems in other regions of Earth. On one-fifth of the irrigated land in the USA (South Dakota, Nebraska, Kansas, Oklahoma, Texas, and East Colorado) on around four million hectares water recharge rates are less than those of extraction. Israel and Jordan also use more fossil water than is being renewed. There are similar problems in India (mainly in Rajasthan), Thailand, Mexico and North Africa. One problem that occurs in India is that only better pumps make it possible to extract declining groundwater resources, which poorer farmers can not afford, so they become even poorer. It is also an Indian problem that due to the deeper groundwater and the decreasing opportunities for irrigation there are places where previously it was possible to harvest three times a year, but there are nowadays only two harvests. This has the same effect as if the size of cultivated areas decreased by one-third.[107] During 2-3 decades, groundwater levels have decreased by thirty meters over large areas of North-eastern China (where about one-hundred million people live).

Another problem with agricultural water withdrawal is poor irrigation practices that degrade soils in many areas. An interesting aspect of agricultural water use is that trade in agricultural products also generates significant water use in importing countries, as it indirectly implies water imports (the production of one kg of rice requires 1-3 m^3 of water, and one kg of wheat 1 m^3). Agricultural water use has one more characteristic attribute that multiplies its effect. Water withdrawal in this sector involves the final use of water, as it is either incorporated into products or evaporates or infiltrates into the soil, thus there is no possibility for its further use. Pakistan, Bangladesh, and South Korea have the highest proportion of irrigated areas (above 50%), but India and Japan have also have a high share – over 35%.

As a result of increasing problems with the volume of water that is available, farmers are forced to water using efficient irrigation systems. There are several cost-effective and efficient methods: grooved irrigation systems, water-saving nozzles, and the most up-to-date method: drip irrigation. Through their application a reduction of more than 10% in water consumption can be achieved with less investment and a payback period of 1-4 years. The drip irrigation technique was developed by Israel from the 1960s onwards. The cost of investment is greater, but its efficiency is 95%, thus there is a good argument

[107] In the warm climatic zone, water is almost the only limiting factor for effective farming. If irrigation is possible, production cycles are freely adjustable. On the island of Java, I saw rice planting, semi-grown crops, and harvesting occurring simultaneously.

for using it even on valuable crops. In the case of certain crops under special care sewage water can be used for water-saving purposes.

Water consumption in industry has declined globally over the last decade to 19% of all water use (44% in developed countries, but only 3% in developing ones with a low income), but a significant increase is expected (from 752 km^3 in 1995 to 1170 km^3 in 2025). Compared to agriculture, industry mostly only uses water; however, it often causes serious environmental problems due to water contamination. Industrial wastewater contains and accumulates about 300-500 million tonnes of toxic heavy metal, solvents, and toxic sludge per year.

Industry is the field of use in which the most spectacular water savings have been achieved as a result of various forcing factors. In industrialized countries such as Japan and the US, industrial water use has already declined and production per unit of water has increased considerably. The potential for improved technology can be illustrated by the example of paper or steel production, where water use has been reduced to less than a tenth of the former value per kg of final product. Recycling sewage water also plays a significant role in increasing efficiency – which directly motivates improvements in the efficiency of water treatment too.

The top industrial water user is the USA (nearly 250 km^3 in 2015), the second is China which uses around half of the amount of the USA, while the consumption of other large users is only around 10-20 km^3 and has not changed substantially over the past 1-2 decades. Along with significant economic growth, China's water use tripled between 1985 and 2005, and has remained at the same level since then.

The share of communal water use in total water use is considered by many as an important indicator of economic development, although this is very misleading as water use is more dependent on the climate of a country. Where agricultural water supply is relatively guaranteed by precipitation, and there is no need for irrigation (e.g. in the UK or Switzerland), most water use is accountable to industry and the communal sector. This explains why, for example, in 2014 there was a smaller difference between the average communal water consumption of economically developed and underdeveloped countries (15% and 7%) than among developed countries (e.g. UK 71%, Switzerland 60%, Germany 14%). Due to the large population, China is first and India third in terms of consumption, but due to its high consumption per capita, the USA is second in the ranking. Of course, communal water use per capita is closely related to development.

Communal water use has spectacularly changed over the past one-and-a-half centuries, but especially during the last fifty years. The English toilet started to become popular in the early nineteenth century and then spread rapidly after the epidemics were overcome in the middle of the century. Use of this, as well as changes in bathing culture, required more and more water – but it also caused more environmental pollution problems. Large sewage networks constructed in towns transported concentrated sewage to rivers, but in places where only low-cost solutions for water management were implemented, the contamination of groundwater began, and still has many unpredictable consequences. A book published in 2017 summarizes the problems well: in Asia, Africa and Latin America, faecal coliform bacteria from human faeces significantly contaminate waters.[108]

Due to the rapid growth of urbanization, water consumption has become more concentrated. Communal water use shows the conflict between demand and opportunity, and the gap between developed and underdeveloped countries most clearly. While developed countries have increasingly strict standards for piped water supply and use freshwater (i.e. expensively treated water) for toilet flushing, car washing and garden irrigation, in the developing world even freshwater for drinking has to be bought in from a reliable place. If there is a piped water supply network, it often only occasionally supplies water. It is sad, however, that people in disadvantaged situations often consider their vulnerability to water shortage to be natural.

For a normal standard of living, at least 20-50 liters of clean water per day is required. However, differences in geographical conditions and economic development create large differences in water supply: for example, children born in developed countries today have 30-50 times more water than those born in developing countries. The small amount of available water causes hygiene-related problems in many regions on Earth. Although the situation with hygiene has improved considerably in the last quarter of a century (the number of adequately supplied people increased from 2.8 billion to 5 billion between 1990 and 2015), the number of the population that is unsupplied has hardly changed (at around 2.5 billion).[109]

There are several ways to deal with the quantitative problems with communal water supply. In many parts of the world (in the past and also today) attempts are being made to keep up with increasing demand by ensuring more freshwater supply. This requires either increasing surface water extraction or increasing use of groundwater resources. The latter is dangerous for two reasons: On the one hand, as described above, groundwater extraction generally exceeds recharge, thus it is not a sustainable practice (since it uses fossil waters), while on the other hand, due to its subsurface location, such water is hidden and it is not clear to everyone that the future supply of water is being consumed. According to estimates, half of the Earth's population depend heavily on the use of groundwater resources. It is true that agriculture plays a

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[108] See http://unesdoc.unesco.org/images/0024/002471/247153e.pdf Figure 4 on Page 12

[109] More detailed, real data can be found at: https://ourworldindata.org/water-access-resources-sanitation

greater role in this, but the water extraction of big cities is more spatially concentrated and can cause a spectacularly rapid decrease in groundwater resources. For example, in Beijing and in Bandung (Indonesia), a decline in water level of 1-2 meters per year have been reported, respectively, but the phenomenon has long been known throughout the world. The extensive extraction of groundwater can even cause significant surface sinkage. An illustrative example of this is Mexico City's central basilica, which has not only sunk, but the scale of the sinking of the building structure was so dramatic that a large plumb-bob was placed in one of the domes to document it. The greatest displacement of this device is approximately one meter (Fig. 6.6).

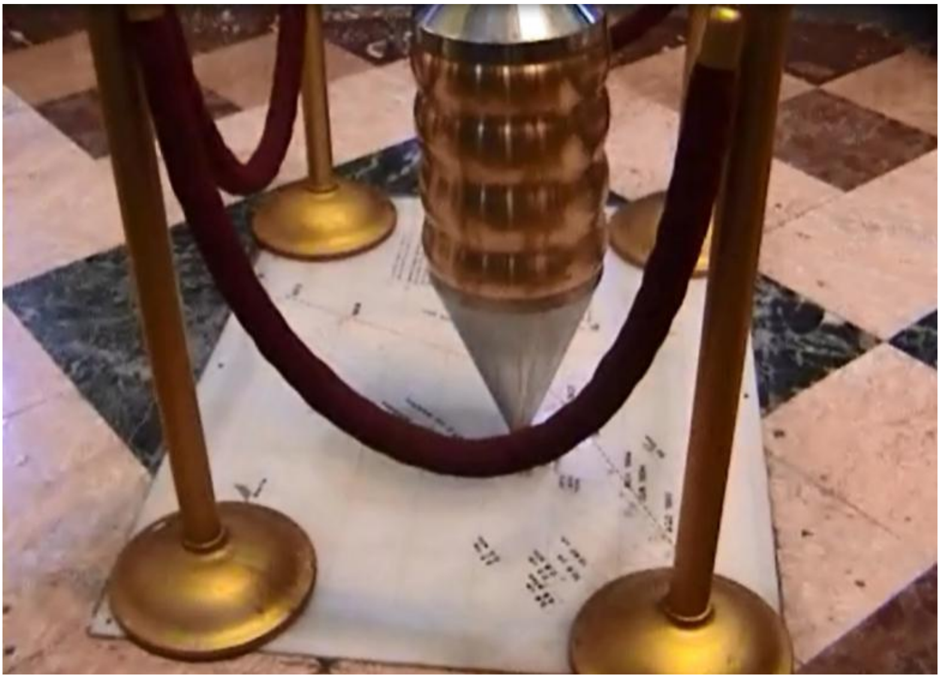

Fig. 6. 6. Uneven sinking of a building structure due to groundwater extraction, as illustrated by the displacement of a plumb-bob in the central basilica in Mexico City (author's photo from 2001).

The most efficient method of controlling water use, however, is not restricting production but by intervention into demand, namely, through prices. There are many examples throughout the world that indicate that by measuring water use and then applying real prices water demand can be effectively reduced. By this method, communal use has been reduced to half in a short period of time in several large cities. The indirect effect of prices has also helped households to increase their efficiency of water use (e.g. water-saving showers, using less water in toilets, recycling treated water, etc.). Increases in water prices undoubtedly affect poorer people. But cheaper-than-real prices do not motivate service providers to develop, thus water reaches fewer people, although the water that is supplied via systems of pipes is considerably cheaper than that sold by private water sellers.

The poor condition of urban water supply systems greatly affects the utilization of water resources. About half of the water supplied in several world cities in developing countries (e.g. Mexico City, Jakarta, Cairo, Manila, and Lagos) disappears from the system due to leaks (and perhaps due to stealing as a result of high prices). There are also, however, not general but encouraging examples for improving the balance of communal water use and saving the best quality water resources. An organized example of this is Singapore, a city-state exposed to water shortages, where for a long time precipitation has been drained from the top of houses not into a drainage system, but into near-surface soil layers. This example has been followed by Tokyo and many cities, and water now drained from the top of hundreds of large buildings is used for irrigation, washing, and fire prevention purposes.

Overall, it can be concluded that the drinking water supply for the Earth's population – despite all the problems – has improved a lot in past decades. Although there were still twenty-two countries in 2015 where more than 10% of the population were using polluted surface waters for drinking, the basic freshwater supply in three-quarters of all countries is ensured. The exceptions are mostly African countries.[110]

Growing water demand in the future can be estimated with a simple calculation. To produce one ton of cereal, approximately one thousand m^3 of water is required, and one person needs an average of three hundred kg of cereals per year (assuming that part of this grain is firstly used as animal feed, and later people consume the meat). *This means that three hundred m^3 of water is required per year to feed a person.* Today, the population is growing by eighty-three million people every year, which means an additional twenty-five billion m^3 of water demand, corresponding to a water flow of 793 m^3/sec. Every year, at least this amount of additional water is necessary only to create a secure food supply.

6.1.2. Dying big lakes, suffering huge rivers

The lack and overuse of freshwater resources is perhaps most spectacularly illustrated by several of Earth’s large lakes and rivers. Environmental problems are indicated by the spectacular decrease in the size of lakes, and significantly polluted rivers. In the following, some consequences of human intervention and natural impacts are demonstrated through some well documented examples.

[110] See: https://washdata.org/sites/default/files/documents/reports/2018-01/JMP-2017-report-final.pdf Figure 4.

The Aral Sea

One of the most complex changes in aquatic environments has occurred in the Aral Sea region of Central Asia over the last sixty years. The alterations are considered to be the worst environmental catastrophe on our planet.

The lake is situated in a continental desert area (annual mean rainfall is 118 mm), and evaporation exceeds precipitation throughout the whole year (Fig. 6.7), thus water supply is determined solely by inflowing rivers. The lake was supplied with water (mostly due to melting) by two rivers from the Tien Shan Mountains – by the Amu Darya, and Syr Darya. After the Second World War, more intensive cotton and rice production commenced using irrigation systems built along the rivers. As a result, the water supply to the lake decreased significantly and its water level began to decrease from the early 1960s onwards. In 1960, the area was still 69.8 thousand km^2, with an average depth of 17 m, and a maximum depth of 69 meters. Its salt content was only around 1% at that time.

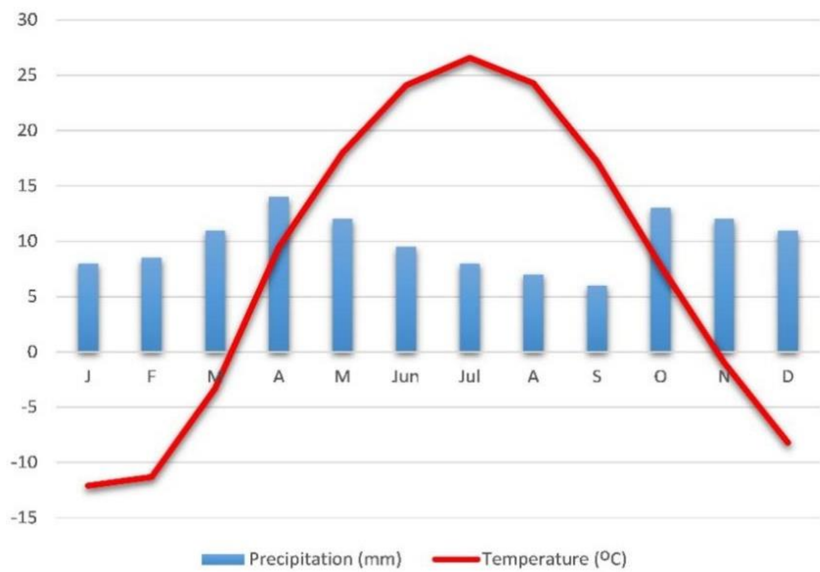

Fig. 6.7. The climate characteristic of the Aral Sea region (using datasets from http://www.cawater-info.net/aral)

In the 1960s, 90 % of the water discharge of the rivers was already being used for irrigation. Previously, the lake received 50-64 km^3 of water in total, 42-56 km^3 from rivers and 8 km^3 from precipitation, while evaporation approximately accounted for 63-64 km^3. For the period 1970–1985, recharge dropped to 22.9 km^3 (16.3 + 6.6), while evaporation only slightly changed (56.2 km^3). The area of the lake has experienced a spectacular and well-documented decline since then (Fig. 6.8).

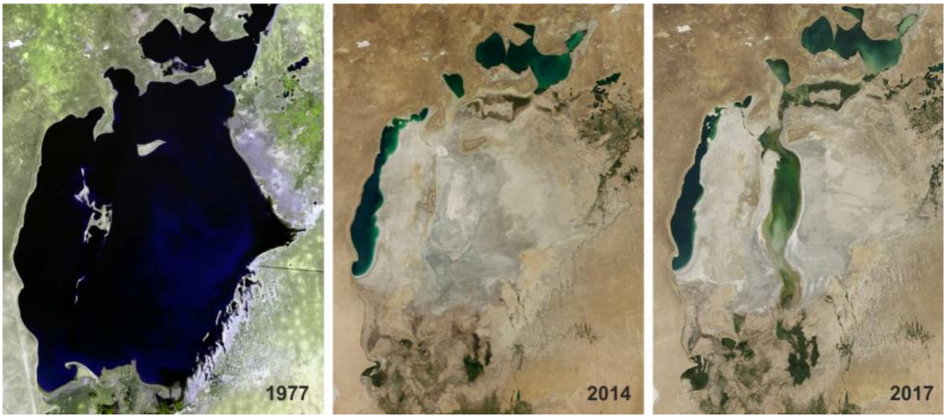

Fig. 6.8. Spatiotemporal changes in the Aral Sea based on Landsat images (1977–2014–2017) (Source: NASA)[111]

In the 1960s, the lake level was decreasing by an annual rate of only 20 cm, which increased to 60 cm in the 1970s and was almost one meter in the 1980s. As a result, the lake became divided into two basins (Big Aral and Small Aral) in the mid-1980s, then its size declined to 10% of the original by 2007, and the lake became divided into four basins. The south-eastern lake had disappeared by 2009, and the south-western lake had turned into a thin strip (at the western edge of the former lake). Although the River Amu Darya slightly recharged the southeast lake in the following years, NASA images in August 2014 showed that the Eastern Basin of the Aral Sea had completely dried up for the first time in modern history.[112] The Eastern Basin is now called the Aralkum Desert. In the past three years (by 2017) the situation improved slightly in the south-eastern basin, and a larger area is under water again. It is a big question how the situation will change in the future.

As a result of the decreasing amount of water, salt content increased steadily[113] (Fig. 6.9), which contributed to the disappearance of wildlife. Seventy-three species of birds, seventy mammals, and twenty-four fish species have disappeared from the Aral region or died out.

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[111] The original source of the images is the NASA Earth Observatory. They can be downloaded from:
1987: https://screenshotscdn.firefoxusercontent.com/images/e6392750-a5e7-4553-95a5-7589371630c2.png,
2014: https://upload.wikimedia.org/wikipedia/commons/7/75/AralSea1989_2014.jpg,
2017: https://earthobservatory.nasa.gov/IOTD/view.php?id=90857.

[112] Photo series of the spatial changes in the Aral Sea in the period 2000–2017 can be found at: https://earthobservatory.nasa.gov/Features/WorldOfChange/aral_sea.php. The changes can also be observed in slideshows.

[113] Salt content reached 9.8% in the southern basin.

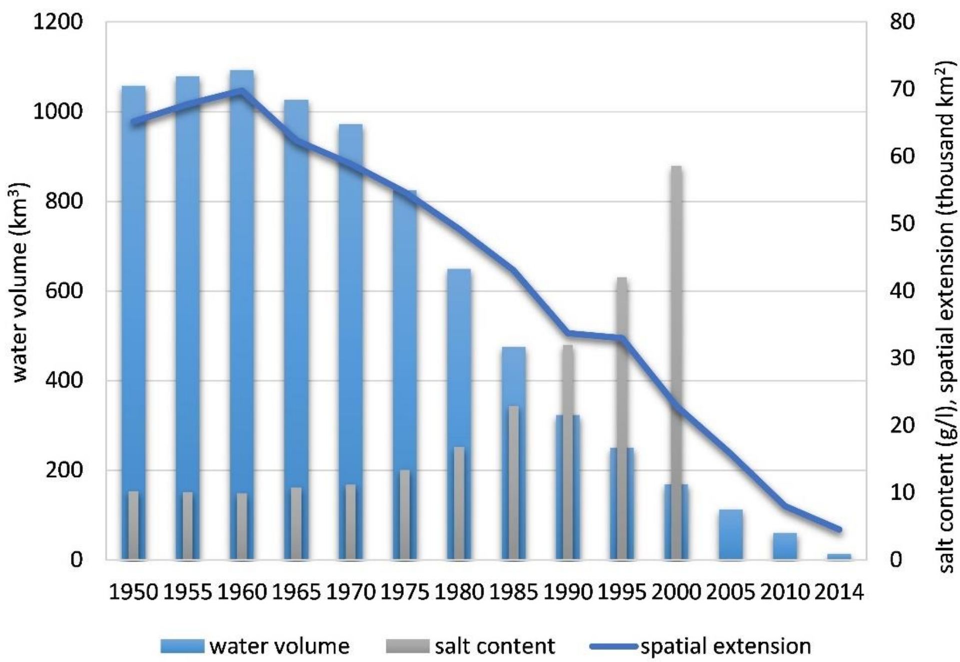

Fig. 6.9. Changes in spatial extent, water volume, and salt content in the Aral Sea in the period 1950–2014
(Data source: http://www.cawater-info.net/aral/data/index_e.htm)[114]

This environmental and ecological change also brought about significant economic and social change. The previously dominant fishing industry (40-50 thousand tonnes per year) had nearly been completely wiped out by the early 2000s (1360 tonnes in 2006). Nowadays, fishing boats that sunk in the shallow water can be found in the desert, and about sixty thousand fishermen have become unemployed. An estimated two hundred thousand tons of salt and sand, often contaminated with chemicals, causes everyday problems at distances of at least 300 km.[115] The very polluted dust was causing severe health problems even in the 1980s. Due to the contamination of freshwater and dust, the number of people suffering from cancer, tuberculosis, hepatitis, anaemia and allergic diseases was high, and in many cases exceeded three times the national average. Salty dust, however, also significantly damages agriculture even today: it destroys pastures,

[114] Data about salt content from 2000 is for the southern basin, while the latter values for the sub-basins are very diverse. Water volume and spatial extension data are aggregated values for the sub-basins after 1995.

[115] The reason for the pollution is that the chemicals applied in agriculture (sometimes in enormous quantities) reached the two rivers that enter the Aral Sea, and accumulated in the decreasing water.

resulting in a significant drop in the number of domestic animals. Due to the lack of job opportunities, firstly rising unemployment and then later significant migration was characteristic of the area. These general social problems were further added to by the fact that the land was inhabited by a minority ethnic group (the Karakalpaks, relatives of Kazakhs) who perceived the dramatic environmental changes as a deliberate form of intervention against their national identity.

This environmental legacy was inherited by five of the Soviet Union's successor states,[116] hindering the elaboration of a comprehensive solution. Due to significant population growth (the combined population of the affected five republics increased from eleven million to over seventy million between 1950 and 2017) the population can not significantly reduce their water consumption, so water recharge is still below the large rate of evaporation from the lake. In September 1995, the five Central Asian republics made an agreement about the sustainable development of the Aral Basin. In spite of the agreed-on interventions, the lake has further shrunk, which is perhaps not so surprising when it is realized that while about fifty million people are directly dependent on irrigation, 'only' 3.5 million people suffer from the consequences of the decrease in the size of the lake. The intention to change has spurred some remedial processes, but they seem to be few. Water consumption decreased slightly, and irrigation efficiency improved, but the size of irrigated areas has increased (Table 6.1). However, the situation has started to improve because, in 1997, the United Nations Environment Programme also donated funds (*International Fund for Saving the Aral Sea*). Within the program, $ 86 million was given by the World Bank and the Kokaral dam was completed in 2005, dividing the remaining lake surface into two parts. As a result the water supply of Syr Darya that reaches the northern lake had increased the water level by twelve meters by 2008.[117] As a result, the water level in the North Aral Sea had increased by 18% by 2018, and its salinity had returned to the original level (8–13 ‰). The latest reports from the remnant lake include discussions about the increase in the fish catch and suggest that a wider variety of fish are now being caught. Optimists (who claim that human-induced ecological damages can be restored) however, should be confronted with the truth: there is no chance that the lake will recover to its original size (that of 1960). In fact, the state of the Aral Sea may even be worse in the long run. The constant retreat of the Asian glaciers that once fed the rivers also affects the lake. There is a little chance that more of the water from the decreasing water resources will enter the lake as it can be seen that declining water use has already significantly hindered the success of agriculture.

[116] The Aral Sea Catchment extends to seven countries (also involving five Soviet republics), but the core area belongs to two successor states, Kazakhstan and Uzbekistan.

[117] There was already a difference of seventeen meters between the lakes in the north and in the southeast in 2014.

Table 6.1. Data about water use in the Aral Sea Catchment (using data from UNEP GRID Arendal)

	1960	1970	1980	1990	1999
Irrigated area (thousand hectares)	4510	5150	6920	7600	7900
Total water withdrawals (km^3/year)	64.7	83.5	120.7	118.1	107.6
Withdrawal for irrigation (km^3/year)	55.2	74.0	108.5	106.0	96.3
Irrigation water use (m^3/hectare)	12240	14370	15680	13950	12190
Agricultural production (billion $)	5.8	8.9	18.3	22.0	17.0
Irrigated area (thousand hectares)	4510	5150	6920	7600	7900

Considering the changes in the Aral Sea, it can be concluded that even although it is located in a desert area, changes in water parameters were smaller until the 1960s. Subsequently, however, the amount of water was influenced by anthropogenic interventions and climate change has hardly played a role in such environmental changes over the past half century.

Lake Chad

At the time this book was being compiled (mid-2018), a social crisis was emerging in the wider environment of Lake Chad. Some think that this is a food and humanitarian problem, but it is even more complex: as a joint result of climatic and social impacts, it is rather an environmental one.

Lake Chad, situated along the southern edge of the Sahara, is in a crisis situation similar to that of the Aral Sea. Although some processes appear very similar, several significant differences can be discovered. Lake Chad is located near the border of a zonal desert and the Savannah. The amount of precipitation along the dry north-eastern shores is also over three hundred mm (in the city of Bol it was between 125 and 565 mm between 1954 and 1972 and the mean was 315 mm). In southeastern parts it is significantly higher (in N'Djamena – in the former Fort Lamy – it is about 650 mm on average – Fig. 6.10). Most precipitation falls during the summer period (mostly in July and August) and the amount of this can exceed potential evaporation for 1-2 months, while most of the year is without precipitation. (Compared to the Aral lake, there are significantly better precipitation conditions in the surroundings.) Thus, the amount of water in the lake is determined by the precipitation in this short period, and therefore its extent and water level show significant seasonal fluctuation (Fig. 6.11) that is strongly related to the shallowness of the lake (it is not deeper than 5-8 m, even in normal periods).

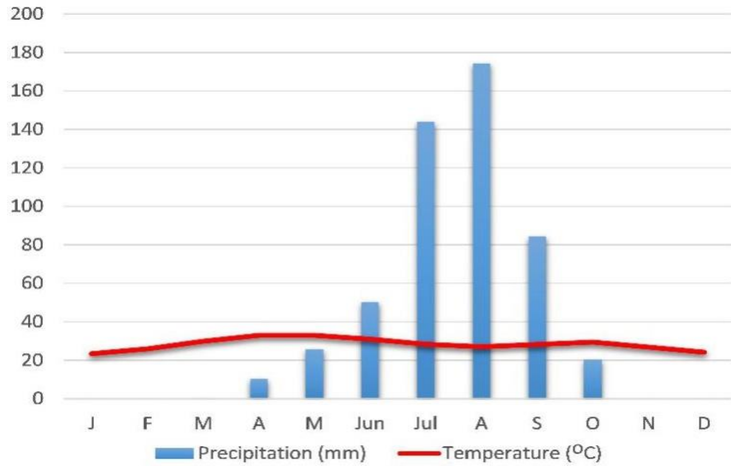

Fig. 6.10. Climate characteristic of the vicinity of Lake Chad: annual variability in temperature (1) and precipitation (2)
(Source: http://www.n-djamena.climatemps.com/)

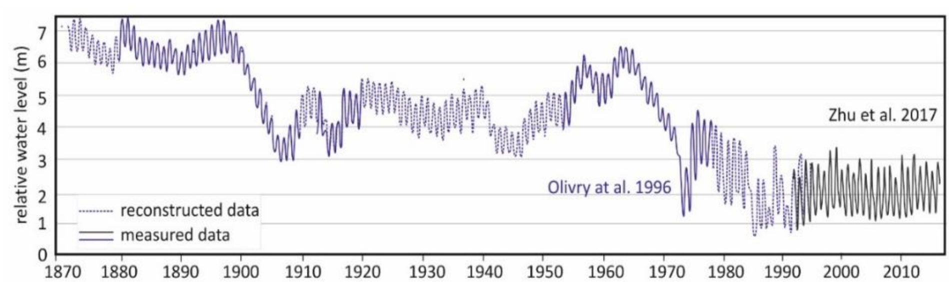

Fig. 6.11. Changes in the water level of Lake Chad in the period 1870–2016
(Source: USGS, including Olivry et al., 1996 and Zhu et al., 2017)

Changes in the water level of Chad Lake over the past one-and-a-half centuries show the differences in precipitation. From the 1870s to the early 1960s, natural rainfall conditions shaped the water level. Annual fluctuation was approximately one meter at that time (a two-month rise in water level was followed by a ten-month decrease due to evaporation). In the last third of the nineteenth century, the lake had a higher water level and a larger surface area, which was followed by a three-meter drop in water level at the beginning of the 1900s after a nearly ten-year-long dry period. In the following half century, with the exception of two drier periods lasting for a few years, fluctuations were relatively even in the lake (two meters lower than at the end of the nineteenth century). From the second half of the 1950s to the mid-1960s, the water level was approximately one meter higher, and was only one meter less than the water level of the previous hundred years, before any major human influence. The following two decades of drought and the sudden increase in water use in the catchment triggered a rapid change. Following the humid year of 1963, Lake Chad went through a huge change, like the Aral Sea, and its area decreased to one-twentieth of the original (!) by 2001 (Fig. 6.12). Migratory semi-nomadic farming had been increasingly replaced by permanent settlements since the 1960s, which required more intensive farming. Along the south-eastern shores of the lake, Nigeria planned a huge irrigation program in the early 1960s, in which fifty-five thousand family farms were to be designed. Implementation of this plan begun in the humid period of 1962-63 and the project, covering the first thousand acres, was successfully completed in 1966. A major part of the program took place between 1974 and 1979, when sixty-seven thousand acres of irrigable area were built. Irrigation was carried out using channels and pumps, mostly using gravitation. However, the irrigation plan that was developed was made in line with the actual water level. When the water level fell below two meters, irrigation was not possible. As a result, the system could only be used on seven thousand hectares for six years during the first decade of operation. It can be observed from Figure 6.11 that planning was done according to real historical data, since in the previous hundred years the water level had always exceeded the amount estimated to be needed. However, the water-level decreasing impact of irrigation along the river, and the extraordinary drought that extended over the entire Sahel zone had not been encountered before.

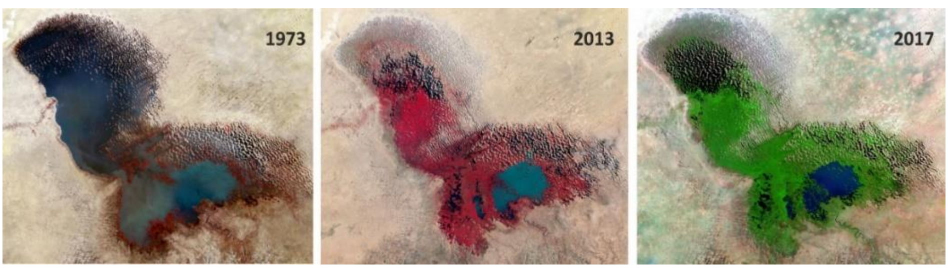

Fig. 6.12. Spatiotemporal changes in Lake Chad 1973 – 2013 – 2017 (Source: NASA)[118]

[118] The images from 1973 and 2017 can be downloaded from: https://earthobservatory.nasa.gov/IOTD/view.php?id=91291&eocn=related_to&eoci=related_image, the images are false-colour composites, 2013: https://earthshots.usgs.gov/earthshots/sites/all/files/earthshots/2013-FullMosaic_LakeChad_Main%28chs.%201%2C2%2C3%29.png

A few years later, Cameroon, Chad and Niger also launched large irrigation programs. Due to the drought in the 1970s, irrigation along the Chari River also increased and, as a result, river discharge was reduced by 75% (in N'Djamena city, Chad). Meanwhile, several settlements were built at the lakeside (in the Nigerian section alone the number increased from forty to one hundred between 1975 and 1988).

Due to the distribution of precipitation and the shallow lake depth, the average water surface of Lake Chad decreased from 10,000 km^2 (mean extension in dry years) to 1350 km^2 in 2001 (1982: 2276, 1994: 1756 km^2), and due to the smaller water surface its annual fluctuation increased. Until the 1970s, interannual fluctuation hardly exceeded one meter, but later fluctuations of more than two meters were not rare. The open water surface of the lake almost disappeared over twenty years (1960–1980). Modelling of the processes showed that in the first half of the period irrigation was responsible for only 5% of the impact on the water level decline, but later (when the irrigated area was quadrupled) the effect on the changes was around 50%.

Since the beginning of the 1990s precipitation was around the average of the previous period; moreover, a slight increase in precipitation has been observed in the last thirty years (Fig. 6.13). The water level and the lake's spatial extent have both 'stabilized' at a relatively low level. The minimum area in June is now around 1427 km^2 and the maximum in November is around 1465 km^2, while the seasonal alteration in spatial extension is 38 km^2.

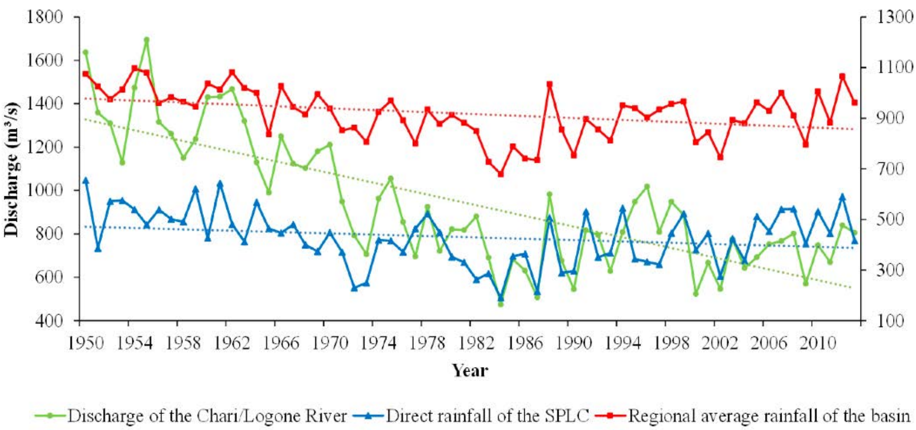

Fig. 6.13. Changes in precipitation and discharge in the southern part of Lake Chad (1950–2014) (Zhu et al. 2017)

Due to the smaller volume of water and surface area of the lake, significant ecological changes have also occurred: vegetation-covered areas have decreased in extent and been altered. In 2001, roughly half the area of the lake was covered by non-native species. With the $19 million support of the UNDP

Global Environment Facility, a program was implemented to reduce adverse impacts between 2003 and 2006. Its main goals were to reverse the land and water degradation trends in the Lake Chad basin ecosystem, and establish mechanisms for land and water management.

In addition to the complex environmental crisis described above, a social crisis has also impacted the region in the past one-and-a-half decades. A relative decline in incidences of famine has accelerated population growth in the past decades, thus the average age of the population was 15-18 years in the concerned countries in 2015. In recent years, it has become increasingly apparent (and has been regularly stated for at least ten years) that there are not enough environmental resources to support the large population. Food insecurity and malnutrition have reached critical levels. At the beginning of 2018, more than seventeen million people were living in this region, and about 7.2 million were suffering from severe food shortages (though this was temporarily reduced to 4.5 million as a result of the good harvest in 2017)[119]. The bad overall situation is exacerbated by epidemics (last time, cholera). The difficulties associated with the phenomenon are also indicated by the fact that 2.3 million people are intending to leave the area. A newspaper article summarizes the situation as the following: '*When water sources dry up, hunger, displacement, and radicalization follow…'*.[120] Terrorism is spreading among the dissatisfied people, often initiated from outside, intimidating the vulnerable population. Sad evidence of this fact is that, in 2017, at least 135 children (five times as many as in 2016) were forced to act as suicide bombers using explosives strapped to their bodies. Unfortunately, governments can not act effectively as regards this issue either. The unstable situation may lead to even greater migration.

The following can be stated about the similarities and differences between the problems associated with the Aral Sea and Lake Chad: Geographically, the process is similar: two of our largest lakes have significantly decreased in size almost in parallel. Among the reasons, the role of human intervention (in terms of the over-utilization of water resources for agricultural purposes) is of high importance in both cases, but in the case of Lake Chad, the anthropogenic effect was enhanced by a climatic effect.[121] At both lakes, attempts were made to mitigate the unfavourable processes through development programs. Although the results had local successes, they were more likely only to stop the damaging

[119] Among the countries of the region, Nigeria is the most affected (two-thirds).

[120] https://www.internationalrivers.org/resources/lake-chad-s-water-crisis-the-new-yorker-16604

[121] According to research published in 2017 (https://earthobservatory.nasa.gov/Features/LakeChad/), a stronger relationship was found between the water-level changes and precipitation anomalies at Lake Chad. The connection between the calculated 1 cm anomaly in precipitation for the Sahel region and the 2 m variability in the water level, however, is questionable.

processes and more or less stabilize the size of the lakes – at a small fraction of the original size compared to the original water surfaces.

The difference is also that, in the case of Lake Chad, the directly affected population is larger and the central role of states is much smaller; furthermore, the area is also affected by terrorism. There is no chance that the surrounding countries will be able to solve their problems in the foreseeable future, and an economic crisis and humanitarian catastrophe is approaching – perhaps even in the short term.

Considering the future of the two lakes over the longer-term, it appears that they may develop differently. The future of Lake Chad does not seem bright, but due to its climate the state of its water supply may not be as hopeless as that of the Aral Sea. After a long dry period in the Sahara, the more efficient use of water resources can help with regeneration. There is and will be more water, but the big question is whether the people living in the area will be able to take advantage of the opportunity and can adapt their water use. The future of the Aral Sea is less encouraging due to current global warming trends. It is true, however, that the source of the problem so far has almost entirely been human intervention. In the future, however, less water is expected to arrive from melting mountain regions, and the temporal distribution of precipitation may become even more uneven.

Lake Urmia

Lake Urmia is one of the largest salt lakes on Earth (length: 142 km, width: 54 km, depth: 6-15 m), and the largest lake in Iran, previously characterized by a spatial extent of 5775 km^2 in the 1990s. Environmental problems there are similar to those with the previously described Aral Sea and Lake Chad – but the changes occurred approximately thirty years later. It can be stated that individuals failed to learn from the mistakes made by others, although the comprehensive water management solutions that were implemented may serve as good examples for other areas.

The endorheic lake lost 0.6-1 meters of water every year through evaporation, and its salt content was high even before the environmental changes (8-11% in spring, 26-28% in late autumn). Due to the pleasant environment and the beneficial health effects of salt water, it was a favourite area for tourism. The level of water was very high from the beginning of the 1970s to the mid-1990s, but began to decline rapidly around 1996 (decreasing nearly seven meters in fifteen years) (Fig. 6.14). Its area decreased to 10-12% of the original (Fig. 6.15) and salt content increased to 340 g/l (ten times the world average, and similar to that of the Dead Sea). The lake's wildlife changed significantly, and tourism dropped dramatically. Since local people knew of the sad example of the Aral Sea, they demanded effective intervention by the government, and also demonstrated to avoid environmental catastrophe.

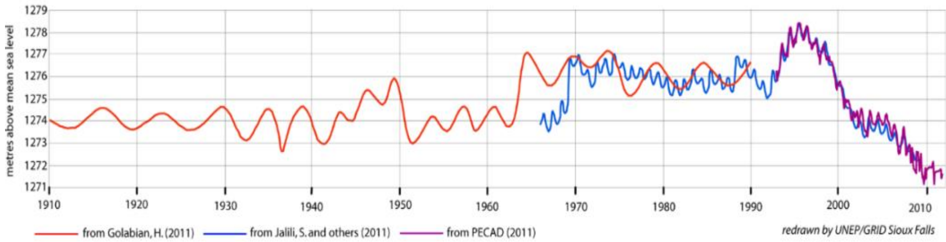

Fig. 6.14. Changes in the water level of Lake Urmia (1910–2012) (Source: UNEP 2012)

Fig. 6.15. Changes in spatial extent of Lake Urmia on satellite images 1998 – 2014 – 2017 (Source: NASA and ESA)[122]

A brief assessment of the results of research suggests that the chain of causes is complicated, but human impacts outweigh natural causes. Annual rainfall at the lake is generally around 250-450 mm, and its changes were previously less obvious in terms of the water level of the lake. Towards the end of the 1990s, however, the level of the lake fell rapidly during a somewhat drier period. Assessments revealed that it was not precipitation but runoff that had decreased significantly (Fig. 6.16). In addition, large lakes in the near proximity, such as Lake Van in Turkey, and Lake Sevan in Armenia, did not change significantly (although their basins are deeper). However, if we look for anthropogenic causes, we can identify more.

[122] Original source of images: NASA Earth Observatory. Images from 1998 and 2014 can be downloaded from: https://i.guim.co.uk/img/static/sys-images/Guardian/Pix/pictures/2015/1/23/1421981981426/f5f5fe26-9b9b-4325-a663-82d95624a82d-2060x1406.jpeg?w=1225&q=55&auto=format&usm=12&fit=max&s=319b13e7546ac11e4ff66d0670b27a08, ESA Earth Watching, 2017: https://earth.esa.int/web/earth-watching/image-of-the-week/content/-/article/lake-urmia-iran

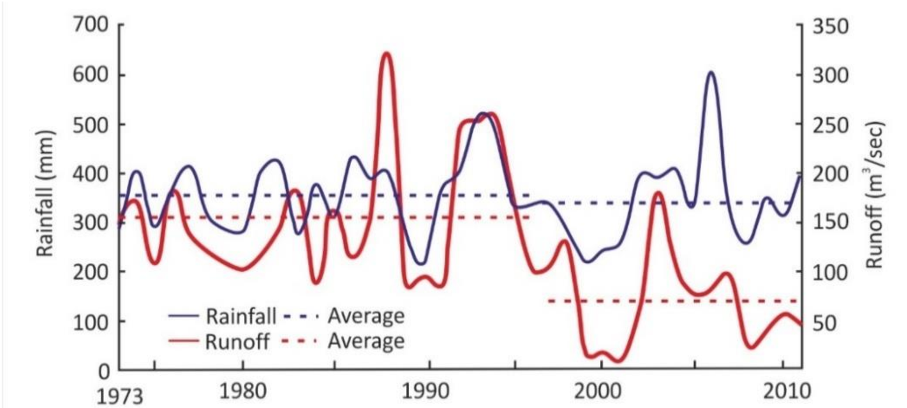

Fig. 6.16. Precipitation and runoff conditions at Lake Urmia (1973–2011) (Farajzadeh et al., 2014)

The decline in drainage was due to the large increase in agricultural withdrawals associated with the 6.5 million people living in its catchment. To support appropriate water use, several dams are now being used to retain the water in the catchment, and there are further dams in the planning or construction phases (Fig. 6.17). Water retention is necessary, since freshwater that enters the lake can not be used when mixed with the lake's already salty water.

A road that goes through the lake (apart from a 1.5 km long section) has caused another problem by dividing the lake by acting as a dam. Due to the road, the natural water circulation in the lake has ceased (because the lake was split into two), resulting in the warming up of the southern shallow basin and more rapid evaporation. This has resulted in its drying out. 'The fickle finger of fate' is the fact that the environmental degradation of the lake occurred in the same country that the Ramsar Convention on Wetlands was signed in 1971.

The social component of Lake Urmia's environmental problem is similar to that of the Aral Sea, because it has also an ethnic dimension: there are a large number of Kurds and Armenians living in the area (although their numbers are much larger here).

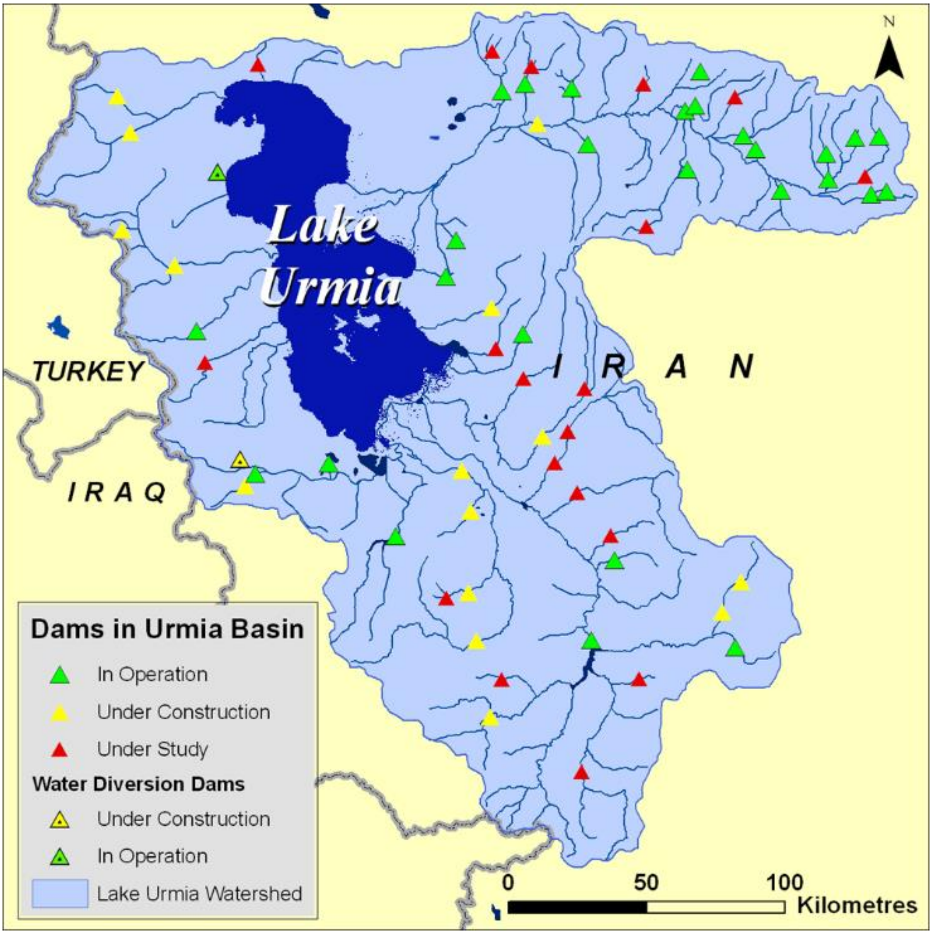

Fig. 6.17. Dams existing, under construction, and under investigation in the Urmia Basin (UNEP 2012)

Although the Iranian government did not allow large-scale public protests, it began to find solutions and seek financial resources for managing the problem. As a first step, from the state's own resources (about $ 500 million) they started implementing the most important water management tasks in 2014 (reducing the water use of farmers, environmental restoration). Subsequently, with the support of the United Nations Development Program (UNDP), the FAO and the Japanese Government, a $1.3 billion project called the Urmia Lake Restoration Program was launched in 2016. The program is based on the approach of integrated river basin management, and is aimed at effective water management, increasing drought preparedness, and obtaining new water resources (from outside of the basin). Farmers have introduced new irrigation methods and moisture-retaining cultivation techniques. The success of the program was strengthened by a strong central government and country-wide implementation (in its main elements). Although it seems incredible, positive changes quickly occurred. In March 2017, a foreign expert reported on the results with satisfaction: Lake Urmia is coming back to life slowly but surely.[123] A quarter of a century ago, for example, the lake had thirty-one billion m^3 of water. When in its worst condition, the volume of water had dropped to only half a billion m^3 in 2013, but by 2017 the water resource was around 2.5 billion m^3. The water surface had also increased from the minimum of 500 km^2 to 2300 km^2. Now, although the water is still shallow, the wind does not blow the salt onto the surrounding lands, settlements, etc. The changes are already visible in the satellite images from 2017 (see Fig. 6.15, above). Although the planned system of drainage from external areas was only partially implemented (the Silveh Dam), the first steps have been taken to implement comprehensive solutions to the environmental problem. Perhaps this can be an example to other parts of the world in the future.

Poyang Lake

For some years it seemed that China's biggest lake, with a spatial extent of 4,500 km^2, was experiencing the kind of critical conditions that had occurred at the previously described lakes. Lake Poyang is naturally linked to the Yangtze River. It plays a major role in the water supply of the region and it is an important winter resting place for about half a million migratory birds. The lake began to dry out at the beginning of the 2010s, turned into a swamp, and its basin later became pasture. Stabilizing the water level with a dam was also considered. There were thought to be several reasons for the changes: the large production of sand from the riverbed, the impact of the Three Gorges Dam on river discharge, and longer drier periods. In the autumn of 2016, for example, the period of low water level in the river began fifty days earlier than in an average year, and spectacular photos documented the drying out of the lake.[124] In July 2017, a huge flood not only stopped the drying out of the lake, but also caused a significant flood.[125] Here, the real solution – the lake's proximity to the great river – was ensured by nature. However, the situation also drew attention to the consequences of human intervention.

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123 http://www.ir.undp.org/content/iran/en/home/presscenter/articles/2017/03/22/lake-urmia-comes-back-to-life-slowly-but-surely.html

124 https://asterweb.jpl.nasa.gov/gallery-detail.asp?name=poyang, and http://www.dailymail.co.uk/news/article-3904648/China-s-largest-freshwater-lake-three-times-size-London-dries-drought.html

125 http://www.xinhuanet.com/english/2017-07/13/c_136441164.htm

The examples of the previously presented three lakes are only the tip of the iceberg. Several lakes hundreds of km² in size have disappeared or decreased in extent in the past decades. In Egypt, fish have died out in Lake Manzala due to industrial pollution, and its spatial extent has decreased significantly. In Nicaragua, Lake Managua is biologically dead due to urban wastewater pollution. In Cambodia, Lake Tone Sap is threatened by mud accumulation due to deforestation. People are already farming a large part of the former Lake Faguibine (in Mali). Several other examples can also be mentioned. It is true that the life of lakes is very short in geological terms: without human intervention, many of them would have disappeared in the last half a century. Goose Lake (USA) and the surrounding lakes have been renewed under humid conditions and then dried out again in dry conditions for a long time. This seems to be a natural process. However, due to irrigation for farming in the surroundings of the lakes[126] it seems that the water resources of the area are partly being used up in farming (which also involves extracting water from groundwater resources) so this activity may even be playing a partial role in the process.

The environmental problems of lakes not only result from changes in water resources, but also from pollution, as was seen from the previous examples. For example, Lake Victoria, the largest lake in Africa, is currently threatened in three major ways: overfishing, accelerated eutrophication due to sewage water, and the aggressive impact of the Nile perch – an introduced species – on wildlife. It is true, however, that over the past decade the lake was also exposed to an increase in the water use of the Nalubaale Power Station, located at the outflow point, thus Uganda is also responsible for a decrease in water level of one meter. However, most studies have found the main reason for these changes was variation in precipitation.

Through these examples we have attempted to draw attention to the fact that well intentioned but not sufficiently well considered human interventions can cause enormous environmental damage, and the consequences often accrue to those who initiated the process, or those who have an interest in the outcome of the interventions. The examples have also shown that anthropogenic influence, together with natural influence, may disguise human responsibility or 'excuse' it to a certain extent. However, it also seems that systemically considered interventions can help mitigate environmental disasters, and at least partial successes have already been demonstrated. However, in addition to financial resources, strong central management seems to be essential.

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126 https://earthobservatory.nasa.gov/IOTD/view.php?id=86358&eocn=image&eoci=related_image

The Yellow River (Huang He)

Fluvial ecosystems are threatened almost everywhere due to unsustainable development and the excessive use of freshwater resources. Half of the five hundred largest rivers on Earth are very polluted and overused, and there are places where there is a risk of them drying out. Since the 1990s it has increasingly been reported that big rivers such as the Yellow River, the Colorado River, the Nile and the Ganges no longer reach the sea during longer or shorter period of the year.

In the 1990s, the water scarcity in the Yellow River was the focus of attention many times. The sixth longest river on Earth (with a length of 5464 km) dried up along a several-hundred-kilometer-long section in several years, thus the river did not reach the sea for a period of one or two hundred days. A doubtful accolade was achieved in 1997 when the riverbed remained dry along a 687 km section, at the Li-Jin station the riverbed was dry for 227 days, and there was no discharge to the sea for 330 days. This was, however, not the result of an extreme year (Fig. 6.18). There were some antecedents to this in the 1970s and 1980s, but the situation became general in the 1990s.[127]

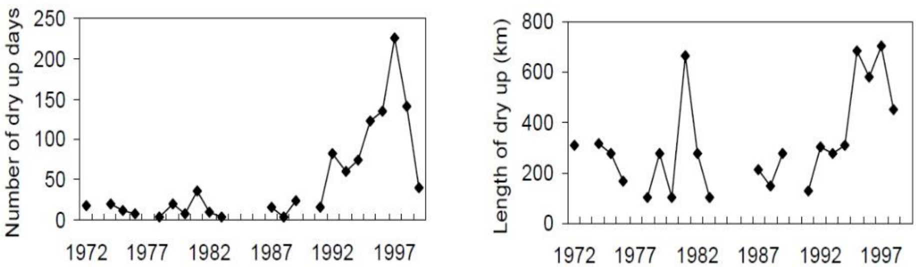

Fig. 6.18. Number of days and length of dry spells of the Yellow River at Li-Jin station (1972–1999) (Fu et al. 2008)

Assessment of the causes of the natural phenomenon clearly shows that social factors are responsible. In 1950, an area of 0.8 million hectares of agricultural land was irrigated in the river basin and irrigated areas exceeded 7.3 million hectares in the early 2000s. Agricultural water withdrawals were coupled with increasing industrial water use and pollution. Although natural runoff decreased slightly for climate-related reasons, the shortage was increased substantially by water extractions (Fig. 6.19).

[127] It should also be mentioned that China's former isolation from the world did not provide much opportunity for international recognition of the problem.

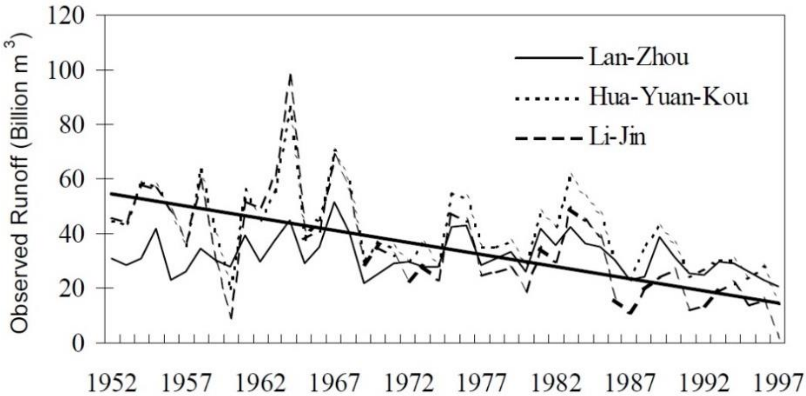

Fig. 6.19. Measured runoff of the Yellow River (1952–1997) (Fu et al. 2008)

The situation did not improve significantly later. According to a contemporary estimate, the 8.2 billion m^3 of water in the river during the first seven months of 2003 had declined by 5.5 billion m^3 in the worst dry season of 1997 and was probably the lowest amount recorded in the past half century. Thus, discharge was less than predicted water use. According to projections, in a year with a typical amount of annual rainfall, 4 billion m^3 of water was estimated for 2010.

China has taken significant steps to alleviate the problems that have emerged in the past decade. A law which was drafted in 2008 and revised in 2015 will support improvements in water quality through better regulation of waste water management (if local authorities enforce this with sufficient rigor). However, the likely future is well illustrated by an assessment from 2016: more than half of all Chinese rivers are overcontaminated water resources, a situation for which industry is largely responsible. Just the waters of the Yellow River alone are threatened by thousands of petrochemical factories. More than 80% of water supplied from rivers is currently unsafe for drinking or bathing. To mitigate these quantitative problems, comprehensive programs have been implemented, the main element of which involves sharing water between different river basins (although this can also create environmental and social risks).

The Colorado River

In the case of the Colorado River, the impacts of effective human interventions and climate change on water resources are well separated in time. This is why research from recent decades considers the latter much more important, and often forgets about the former. Investigation of the water discharge going back one hundred years shows that, following the building of the two most significant dams in the middle of the 1960s (a total of fourteen dams were built on the river), natural changes could hardly be observed in the river. The reservoirs that belong to the large dams are able to hold back most floodwater, thus in the first third of the twentieth century flood peaks fell to a third (from 2500–3700 m^3/s to 800–1100 m^3/sec) of their former volume over the last eighty years (Fig. 6.20). Numerous photographs illustrate the periodic drying up of the Colorado River Delta, and how in several years water discharge has been close to zero (Fig. 6.21).

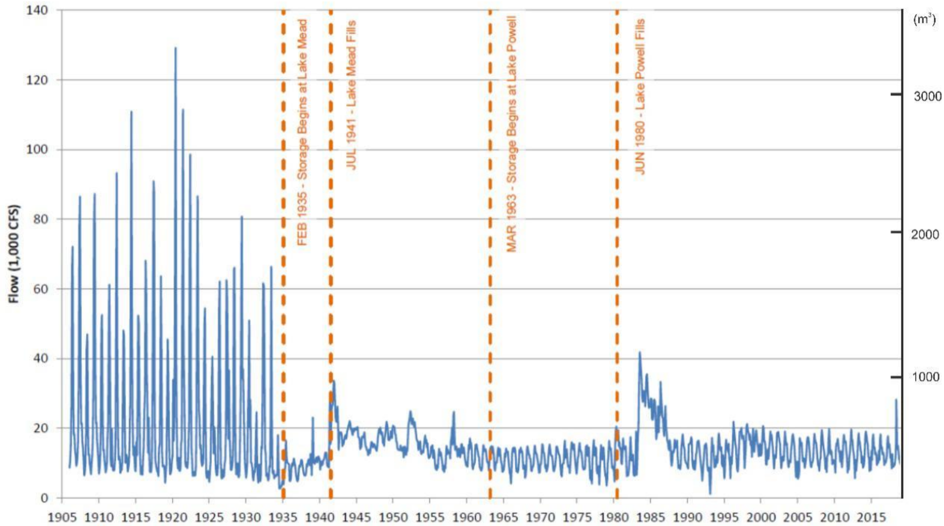

Fig. 6.20. Changes in the discharge of the Colorado River at Hoover Dam (1906–2017) (Source: USBR,[128] supplemented)

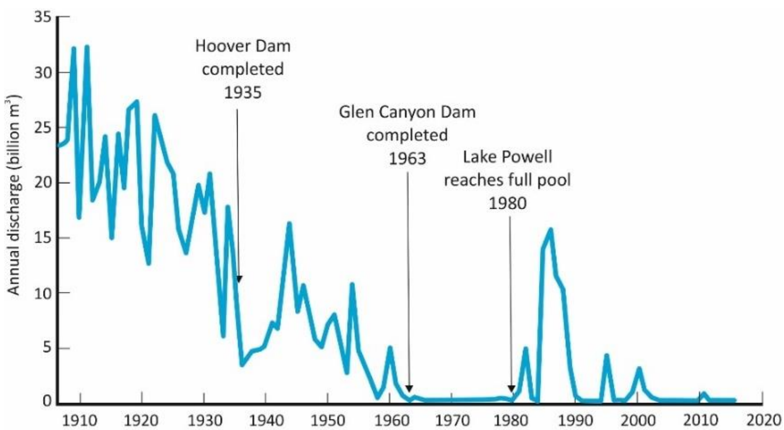

Fig. 6.21. Mean annual discharge of the Colorado River (1905–2016) (billion m^3) (Miller – Spoolman 2012, supplemented with USGS data)

[128] The figure is available at: https://www.usbr.gov/lc/region/g4000/fbhd.pdf, 2017 data are from USGS Water Resources. The original data was in units of 1000 cubic feet.

The dams can turn the uneven interannual discharge into a near constant flow, thereby ensuring a safer water supply. Based on this, an improved (irrigated) agricultural system has developed, and in a hundred years Las Vegas has grown into a city of two million people in the desert. Although the water consumption of the city has been reduced by two-thirds in the past decade out of necessity, its survival is ensured by the two big dams.

Nowadays, about forty million people depend on the water supply from the Colorado River. A study made a few years ago showed that, due to climate change, available water resources are around 80% compared to those of the twentieth century. Long-lasting dry periods follow each other. The river's water resources are overused, and it is news when the river reaches the ocean.[129] Settlements and agriculture (which currently use 70% of all water resources) are forced to compete for water.

Nile

The sediment from the annual floods of the Nile, as known from our history studies, made the soils fertile along the shores and ensured a safe source of food for those who lived there. Due to a growing population and to ensure shipping and cotton production, it became necessary to hold back the river's flood water due to the extreme discharge. First, smaller dams were built in the middle of the nineteenth century near the mouth of the river, while in the first half of the twentieth century several more dams were built. A hydroelectric power station (345 MW) was connected to the (first) Aswan dam that was built at the beginning of the century, which was later rebuilt twice. Egypt, which became independent in 1953, needed more electricity and water, which led to the construction of the new Aswan dam. With the construction of the dam, 2100 MW of electricity was supplied to the country, but the river flow regime was fundamentally altered due to the retention of water in the thus-established Lake Nasser[130] and the dam construction. Annual flood peaks almost disappeared, the water regime became more even (a lower discharge), and the maximum level of water transport could start 1-2 months earlier (Fig. 6.22).

The significant changes in river flow regime have caused more environmental problems: nutrient-rich sediment does not reach the land during flooding (it sediments out in the lake) and, due to the decline in food, the fish population in the delta region has also shrunk. Due to the low water discharge the salt water at the river mouth of the Mediterranean Sea causes

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[129] At the time of compiling this book: http://www.kpbs.org/news/2018/feb/19/few-weeks-colorado-river-reached-ocean-will-it-hap/

[130] The world's second or third largest reservoir, with a capacity of 169 km^3.

soil salinization, and contaminants in the river cannot be diluted. Creating a safer water supply, therefore, has a serious environmental effect, even over a shorter period of time.

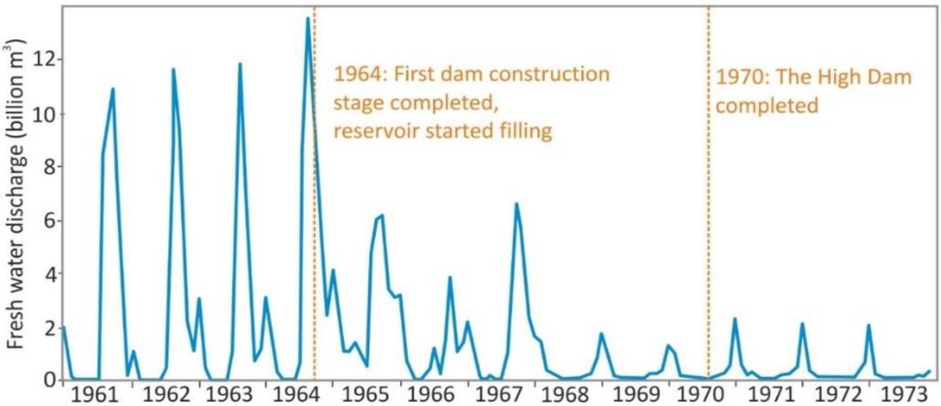

Fig. 6.22. Changes in Nile River water regime as a result of the Aswan Dam (1961–1973) (Source: using Saraf El Din 1977[131])

6.1.3. Reservoirs and big dams

The above-discussed examples of rivers showed that humans can take advantage of the highest rate of rainfall on land if flood water can be retained in greater proportions. However, as seen above, this can have significant environmental consequences (accumulation of contaminants, sediment deposition in lower river sections due to a reduction in water volume, and reoccurring low-water periods).

At the beginning of 2018 there were 59,071 registered dams (of which 8600 were large dams[132]), with a combined capacity of 16,201 km^3, which is equivalent to 35% of all annual renewable water resources. Most dams are in China (23,841), the USA (9265), India (5100) and Japan (3118), but there are more than a hundred in a further thirty-three countries. Most of the dams are for irrigation (20,500), power generation (9,700), water supply (7,700) and flood protection (7,300).

The multipurpose utilization of reservoirs may seem logical, but this is also the source of many conflicts. Based on an analysis by the World Resources Institute in January 2018,[133] 40% of the thermal power plants that provide 90%

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[131] The study is available at: https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.4319/lo.1977.22.2.0194

[132] A 'large dam' has a minimum height of 15 m and a storage capacity of at least three million m^3. In the following decades, more than three thousand of these are planned to be built.

[133] http://www.wri.org/sites/default/files/parched-power-india-0130.pdf

of India's electricity production operate in areas with water shortages and are forced to shut down in critical times, thus their utilization declines by 21%. The damage caused by forced shutdown was estimated at $ 1.4 billion over four years. However, due to the increase in energy demand, the water demand of power plants increased by 43% between 2011 and 2016, and will continue to grow over the next decade.

The construction of reservoirs can also pose a serious environmental risk. The most famous example is the catastrophe of the Vajont Dam (Italy) in 1963, which caused more than two thousand deaths. In 1959, the dam failure of Malpas Dam (France) resulted in 423 deaths. There are presently serious technical problems with the Kariba Dam (Zimbabwe and Zambia), the largest reservoir on Earth. In 2007, serious planning problems were reported in connection with the Mosul Dam in Iraq. But big dams can also be seriously threatened by the destructive impact of natural forces. During the 2008 Sichuan earthquake, more than one million people had to be evacuated from the neighbourhood of several dams. In September 2017, Hurricane Maria caused the almost fatal failure of the Guajataca River in Puerto Rico. These selected examples also show that preserving water resources can pose a significant direct threat, but may also have other environmental impacts (e.g. secondary salinisation, and changes in wildlife).

6.1.4. Water pollution as a limiting factor for water use

Humanity is also decreasing already scarce freshwater resources by contaminating them. The problems associated with water pollution (e.g. floating waste on water, odorous channels, eutrophic aquatic vegetation, etc.) are known by almost everybody, as they are to the author of this volume. It was a surprise, however, that during a trip to the Amazon rainforest in 2004, our Indian guide provided us with several bags of water for the one-week journey. Namely, nowadays it is not even sure that one can obtain healthy freshwater in undisturbed humid areas that are not affected by industrial and intensive agricultural activities.

We have previously referred to the fact that many heavy metals and toxic substances are released into surface waters every year, while agriculture is not only the largest subsurface water user, but is at least 70% responsible for such contamination. Polluted water causes many illnesses (causing at least half a million deaths a year[134]), but also degrades wetlands, resulting in the disappearance of many species. Once, the poisoning of wells was an effective

[134] In previous years several million deaths were attributed to polluted water, but according to a WHO summary in February 2018 the total was 502,000 deaths http://www.who.int/news-room/fact-sheets/detail/drinking-water

means of fighting an enemy, but today, despite the desire of mankind, humanity has ‘adoped’ this method – practically against itself – and many clear examples of such practices can be identified. In many cases, the real cause of problems is discovered only several years or decades later.

One of the most serious disasters involving modern industrial pollution was so-called Minamata disease. In the early 1950s, neurological changes and birth defects were experienced in large numbers in a small village in Japan called Minamata, and it later turned out that the reason was mercury poisoning. A chemical factory that produced plastic materials was using a mercury-containing compound as a catalyst. The company presumed that this mercury-sulphate, which is hardly soluble in water, was entering the sea and becoming buried in sediment ‘forever’. However, it was not considered that bacteria in sediments could decompose this compound. During the process, highly toxic methyl mercury was formed at only a very low concentration in the water, but based on its properties it accumulated in the food chain: firstly in fish and clams, and later in the people that consumed these. Thousands of people got sick and at least 1700 deaths occurred. The mercury that had accumulated in fish caused poisoning even fifteen years later, thus a net was used to cut off the bay from sea fish in 1974. (Water quality improved to safe levels only forty years after the pollution event, and the protective net was removed at the end of the 1990s.) However, the situation in Minamata drew the attention of the World Health Organization (WHO) to micro-pollutants. This organization drew up a list of similarly dangerous substances (heavy metals, DDT, PCBs, PAHs, etc.). Another example of environmental pollution is connected to cadmium, another heavy metal, and also comes from Japan. The water in the Jintsu River, containing heavy metals (Pb, Zn, Cd) from the Kamiska mine, was used to irrigate paddy fields. Thus, cadmium entered the food chain, later causing severe changes in bones. Due to the disease, bones lost their structure and almost collapsed. As a result of the pain, patients moaned, so the disease was named ‘iti-itai’ (the Japanese equivalent of ‘wailing’). it was mainly older women who had more children that suffered from this disease.

Although human life was not endangered, one of the most significant water pollution catastrophes connected to a river was the contamination of the Rhine in November 1986. By the 1970s, the river was ‘at the top’ of the rankings of the most polluted rivers, but as a result of an international agreement water quality was normalized in the 1980s. The problem was that a fire started at a Swiss company operating in the chemical industry (Sandoz, Basel), and during the process of extinguishing this about thirty tonnes of agricultural chemicals and mercury-containing compounds (about 200 kg of mercury) were released into the river (in addition to related air pollution). As a result of this poisoning, hundreds of tons of fish died, but in Baden-Württemberg, the area most affected by pollution, 80% of all aquatic fauna was destroyed, although near the river mouth the water was significantly diluted, causing less damage. The different agrochemicals decayed over shorter or longer periods, thus mercury that accumulated in wildlife was considered a real and permanent danger. In 1987, another Rhine Action Plan was launched to improve water quality. In recent decades, several Chinese rivers have been affected by more serious pollution resulting from industrial accidents.

Among examples of water pollution associated with surface waters, the cyanide pollution of the Tisza River (Hungary) is also important to mention. The pollution came from the mining area around Baia Mare (Romania), where an Australian-Romanian company used cyanide technology to extract non-ferrous metals from a spoil heap (a by-product of gold mining that is stored up due to its lower metal content). The heavily polluted sludge that was stored without appropriate care was released from the reservoir due to significant rainfall and caused huge damage to the wildlife in the river – although due to proper provision of information, human life was not endangered. The severity of the situation is shown by the fact that the estimated 105-110 tons of cyanide would have been enough to kill several million people.

Serious problems worldwide are related to inappropriate sewage management that involves simple disposal instead of the safe collection and treatment of waste waters. If an impermeable layer is located near the surface, pollution may only slowly infiltrate into deeper layers and thus may contaminate only near surface groundwater reservoirs. However, there are successful examples of the prevention of groundwater contamination. Merida, a city with nearly a million inhabitants, is located on the highly-permeable karstic limestone deposits of Mexico's Yucatan Peninsula. Without a proper wastewater treatment system waste water that is collected could infiltrate into the presently high-quality karstic aquifers nearly unobstructed, making the water in them practically unusable. Merida's problem is not unique, but clearly shows the types of problems that we are facing. The low level of sewerage facilities and the lack of sewage treatment in many countries reduces the amount of available drinking water not only in big cities but even in rural areas. Every year, hundreds of km^3 of residential wastewater is released into rivers and lakes. In order to use this water again, 6,000 km^3 of clean water would be needed. If the pollution of water continues at its recent level, water resources will be sufficient only to dispose of such contaminants. The situation is particularly serious in underdeveloped countries where 90% of municipal wastewater and 75% of industrial waste water is released into waters uncleaned. In Asia, every river is polluted, as they all run through larger cities. Only the two largest rivers on Earth, the Amazon and Congo, can be regarded as relatively healthy.

Due to the contamination of surface waters, the use of unpolluted groundwater resources is increasing. For a long time, quality problems with groundwater resources were less obvious, especially in poorer, large-population countries, although groundwater may be contaminated because of pollutants of natural origin too. Around the millennium, several areas in Southeastern Asia faced this problem. Wells (usually more than two hundred meters in depth) constructed in the frame of a 'safe' drinking water supply program, produced water with a significant arsenic concentration. Although the first signs were recognized around 1983 in West Bengal (India) when at least two hundred thousand poisonings occurred, probably because of arsenic, the case came into focus in 2002 when it was revealed that a significant part of Bangladesh's population (from thirty-five to seventy-seven million people) could be affected by poisoning. Beside the deaths, at least one hundred thousand people are suffering from poison-related skin effects. *Arsenic in drinking-water* was the title of a 2003 evaluation of the topic – quite rightly. Analyses have revealed that the arsenic concentration of waters is above 200 mg/l in large areas, instead of the WHO recommended 10 µg/l (Fig. 6.23). In 2016, at least twenty million people still were consuming contaminated water in the Bengal delta, and the number of deaths associated with poisoning is estimated at forty-three thousand every year.

This is probably the greatest incidence of poisoning in history. Moreover, background research revealed that the problem is even more serious: it turns out that the entire Himalayan range (North India, Nepal) is affected; moreover, people on every continent are also affected by the problem (e.g. China, Thailand, Taiwan, Argentina, Chile, Mexico, USA, and Hungary), thus *the high arsenic content of groundwater can be regarded as a global problem.*[135]

The situation in Bangladesh also draws attention to the vulnerability of poor countries to environmental issues. In the absence of adequate environmental organizations, equipment and regulations, they can not ensure the safe water supply of the population.

Short-term and long-term interests are also opposed: instead of suffering from rapidly acting diseases caused by surface water, individuals have to choose a slower form of poisoning caused by groundwater (since the two hundred thousand cases of arsenic poisoning mentioned above have not been enough to solve the problem in the last twenty years).

[135] The map at http://www.mdpi.com/water/water-03-00001/article_deploy/html/images/water-03-00001-g002.png shows the location and size of population potentially affected by arsenic in water.

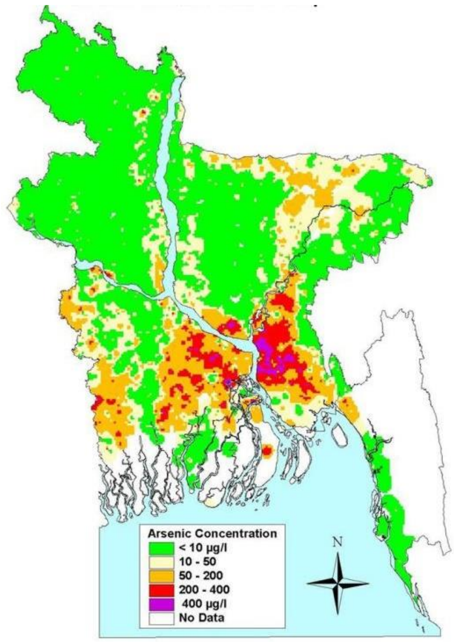

Fig. 6.23. Arsenic concentration in groundwater wells deeper than 150 m in Bangladesh.[136]

6.1.5. Signs of a water crisis

The situation with the uneven distribution of freshwater resources on Earth was introduced previously, showing that a significant part of humanity lives in a water-deficient area. A quote by Benjamin Franklin about this topic ('When the well is dry, we know the worth of water') seems increasingly relevant. By 2018, at least half a billion people were living in areas with very severe water scarcity, so it is almost natural that a search on the internet for the term 'water crisis' will turn up severe water scarcity problems for almost every year. Year by year, new areas are faced with a situation of water scarcity, thus offering a broad overview of this problem is not a target of this chapter, although a few examples are selected to indicate the variety of problems.

Of course, comprehensive information like the fact that 'nearly eighty million in India, seventy-three million in Pakistan, twenty-seven million in Egypt, twenty million in Mexico and Saudi Arabia, and eighteen in Yemen are suffering from water scarcity' is also meaningful. However, the problem is made much more tangible if the water supply problems of large cities that are not inherently water scarce are considered. At the time of writing, the critical water scarcity of

[136] Source of map: https://www.geog.cam.ac.uk/research/projects/arsenic/bangladesh1-small.jpg

Cape Town in South Africa was one of the leading items in the media. Due to a long-lasting period of drought, the level of water stored behind dams decreased continuously, thus water consumption must be decreased by 60% from February 2015 to February 2018, and the expected 'Zero Day' (when taps run dry in the city) was also estimated to be coming in June 2018. The water crisis was slightly ameliorated by the rain in April, and Zero Day has been postponed until 2019, but without enough rain Cape Town's water supply could still dry up.

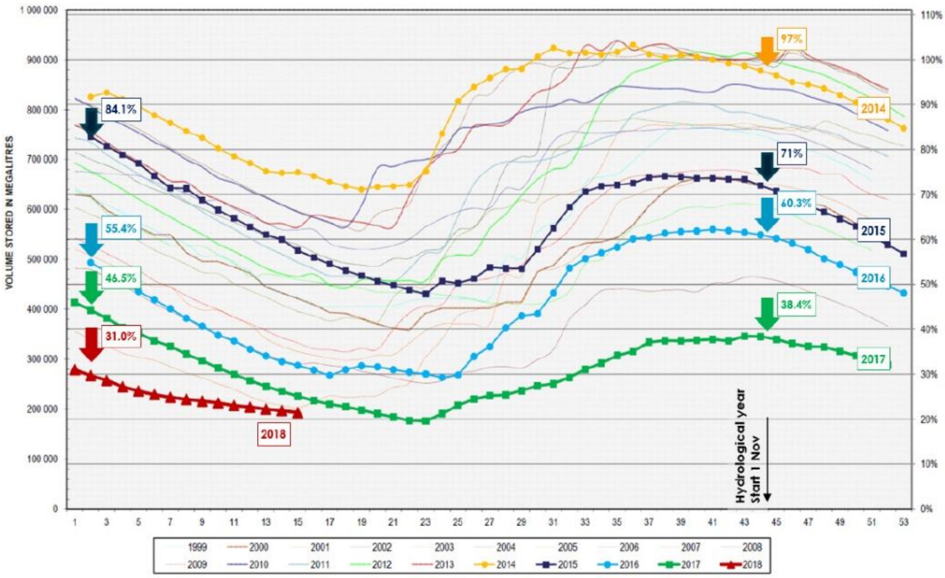

Fig. 6.24. Dam levels around Cape Town from 1999 to 2018[137]

To understand the crisis, the geographical situation of Cape Town should be assessed. Cape Town's water comes almost entirely from rainfall, which is captured and stored in reservoirs around the city. However, in the last 4-5 years the reservoirs could not be filled in the rainy periods, thus available water resources continuously decreased (Fig. 6.24.). Beside the lack of precipitation, the crisis also has a social cause: the population of the city has nearly doubled in the last decades (from 2.4 million to 4.3 million between 1995 and 2018), while the capacity of reservoirs could only be increased by 15%.

The population was prepared for the circumstances of a water shortage through the regular provision of information, thus a panic situation could be avoided and the city even offered guidelines to the public about how to manage their fifty-litre allowance of water (Fig. 6.25). Experts are also trying to improve

[137] Source: http://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/Water%20Outlook%202018%20-%20Summary.pdf

the water balance with different solutions. For example, technologies are being developed to increase the amount of recycled wastewater, and in the middle of 2018 a new seawater desalination plant also came into operation. These solutions, however, make water more expensive.

Fig. 6.25. A guideline to help people manage with their ration of fifty liters of water. Official information from Cape Town[138]

Before the Cape Town case, in 2014 Sao Paulo was forced to significantly restrict water. In 2008, the island of Cyprus and city of Barcelona were both forced to import water. There is hardly a year without a 'cry for help' from a big city: 'La Paz adapts to a world without water' (February 2017), 'India's Silicon Valley faces man-made water crisis' (March 2018), 'Agra reels under water crisis' (May 2018), etc. The reasons may be different, but they indicate the severity of the situation. However, in addition to large cities, many smaller cities across the world are regularly forced to introduce water restrictions, only less attention is paid to these.

Water crises may continue, since due to the dramatic decline in the levels of reservoirs new 'hotspots' are suspected. A report by the World

[138] The guide is available at: http://capetowncarnival.com/wp-content/uploads/2018/02/45422-City-of-Cape-Town-50-Litre-Life-campaign-FA-002.jpg

Resources Institute in April 2018[139] draws attention to many such sites. For example, the Sardar Sarovar reservoir in India which supplies about thirty million people with drinking water decreased by one-third due to the water shortage in 2017, while the water resources in the Al Massira dam in Morocco have dropped continuously over the last three years and the water volume hardly exceeds one-third of total capacity (potentially affecting seven hundred thousand people).

There was an apparent contradiction during the great drought from 2012 to 2016 in California. While reservoirs were spectacularly empty[140] and warning signs on highways[141] called attention to the need for water saving, in Palm Springs green golf courses, full swimming pools and 'leisure' lakes, and the 760 l/person/day of water being consumed did not indicate a desire for water-saving.[142]

However, there are situations where it is not the amount of water, but its quality that causes a water shortage. According to a 2007 report, panic-like water buying broke out in the eastern part of China in Wuhan and the price of bottled water increased six-fold in one day because of water pollution. The panic was due to the fact that a quota system was soon to be introduced.

6.1.6. Challenges of seashores and islands

In coastal areas subsurface freshwater reservoirs and salty seawater has a special relationship, and the relationship of salt- to freshwater is of great practical importance. Subsurface freshwater reservoirs, because of their lower density, 'float' on salt water (similar to icebergs) without the mixing of the two types of water. A one-meter-high freshwater column can be balanced with forty meters of salt water. Subsurface freshwater reservoirs on islands have a lens-like shape, which tends to be thinner towards the coast. Taking into account the above-mentioned data, if a subsurface fresh water table develops at a height of ten meters above sea-level, it balances about four hundred meters of freshwater below sea-level (Fig. 6.26). If a subsurface freshwater reservoir is reduced or extracted, salt water starts to

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139 http://www.wri.org/blog/2018/04/its-not-just-cape-town-4-shrinking-reservoirs-watch

140 Changes can be clearly seen on this pair of photos, from the many photos that are available:
https://www.buzzfeed.com/alexnaidus/california-drought-images?utm_term=.lvro9ddxe#.wn9rKaaoM

141 http://www.kpbs.org/news/2016/dec/16/obama-signs-bill-california-drought/

142 Images showing non-water-saving practices: https://www.ibtimes.co.uk/california-drought-above-aerial-photos-show-need-water-restrictions-arid-state-1496483 or: https://www.reuters.com/news/picture/californias-drought-from-above-idUSRTR4XFEB

displace the freshwater in the deeper zone. If water extraction causes a one-meter depression of freshwater, the salt-water/fresh-water boundary increases by forty meters. This is why every coastal area needs to pay special attention to the extraction of groundwater, as careless water management can ruin this important drinking water resource. In some coastal areas and islands where sufficient rainfall falls, rainwater is not allowed to flow directly into the sea but attempts are made to ensure it infiltrates into subsurface layers. A good example of this is Singapore, where rain that falls on two-thirds of the country's area is drained into storage/ reservoirs and the larger part of all precipitation (2166 mm per year) is collected by these reservoirs (Fig. 6.27). In addition, a complete water utilization program has also been developed. However, in order to meet the water needs of the city, 25% of water use comes from desalinized sea water and the country imports nearly 1 million m^3 of water per day from Malaysia according to a long-term agreement.

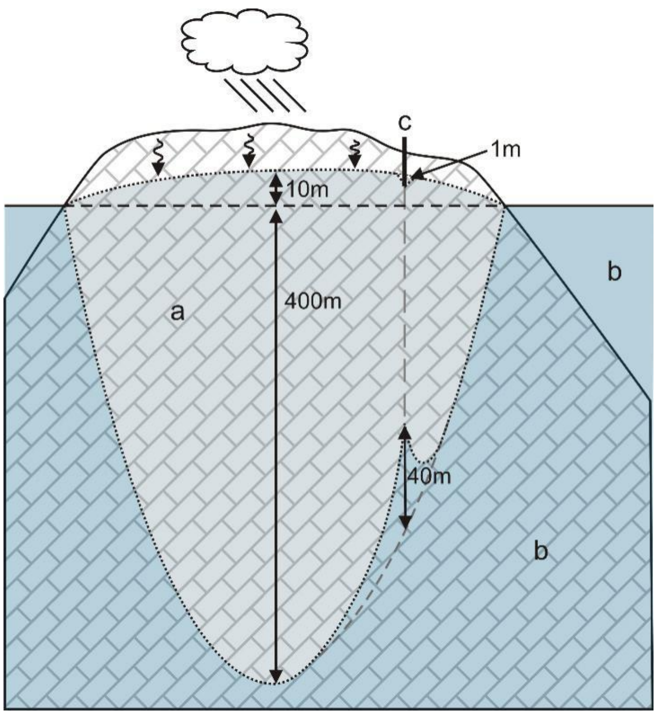

Fig. 6.26. Location of subsurface freshwater (a) and salt water (b) below an island and the changes in their boundary level due to water extraction (c) (exaggerated figure – author’s illustration)

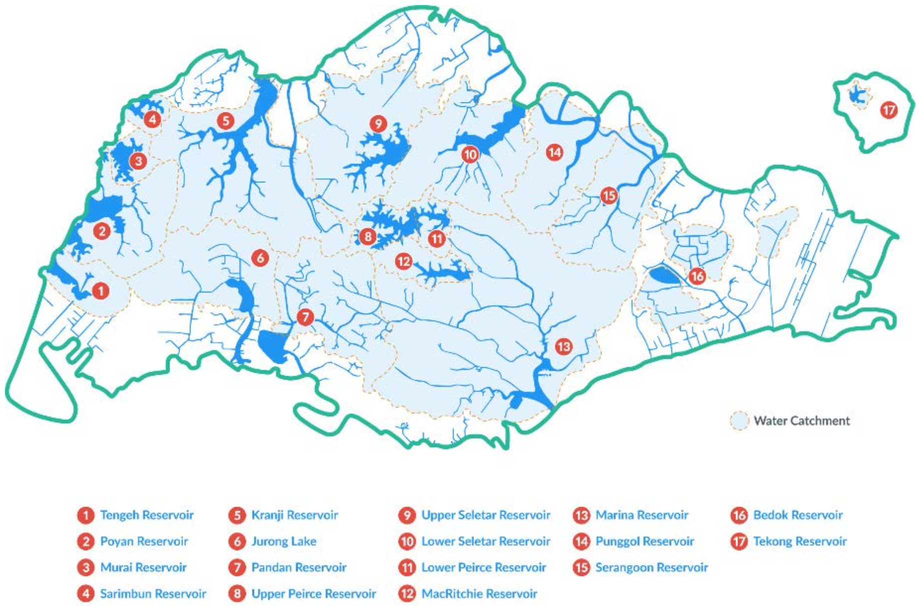

Fig. 6.27. Water reservoirs and their catchments in Singapore (Source: SNWA[143])

Coastal dry desert and semidesert areas where precipitation is low face a much worse, almost hopeless situation. In these areas, the extraction of freshwater from subsurface aquifers is essential. The consequence, however, is almost inevitable – in the near future, salt water will start to displace extracted freshwater. One of the most endangered areas is perhaps the Gaza Strip.

Nearly half of the world's population depends on coastal aquifers, thus the risks related to salt water in these aquifers should be monitored to ensure sustainable future water management. However, scientific articles that deal with the problems of coastal areas are mostly concerned about the future effects of rising sea levels. Sea-level rise obviously poses a risk to coastal areas even without freshwater extraction, but the effect will be much slower (the projected increase in the next hundred years is about forty centimeters) than the freshwater depression caused by water extraction which can transform freshwater resources to salt water within a few months.

[143] The figure is available at:
https://www.pub.gov.sg/watersupply/fournationaltaps/localcatchmentwater, where further information can also be found about water management practices in Singapore.

6.1.7. Flood risk

Freshwater use involves a strange contradiction: while (as discussed above) it is mainly the lack of water that is intensifying global problems, there is an increasing problem with periodic excess water (sometimes in the same areas).

People, who have lived with floods for thousands of years, have tried to exploit their benefits (Egyptian and Mesopotamian river cultures, waterwheels, water transport, etc.) and have continuously adapted to changes in the environment. However, when the population of an area increases and the population has overshot the carrying capacity of an area, it seems a reasonable solution to also exploit usable floodplains. In the nineteenth and twentieth centuries, extensive river regulation and flood protection were carried out around the world, increasing the conflict between nature and humanity. The water transported by rivers flows through a much narrower area when artificial floodplains are created, with several obvious consequences:

- the narrower floodplain of rivers has resulted in an increase in flood levels, shorter flood duration, and additional environmental changes, demanding regular increases in dams,
- shorter and more intensive floods increase channel incision and consequently prolong the duration of periods of water shortage. They also cause ecological and climate-related changes by reducing wetland areas, thus further increasing existing water shortages,
- an increase in flood levels and the expansion of built-up areas on floodplains multiplies the risk of floods and the volume of associated damage.

Floods are one of the most important natural disasters: they are responsible for half the deaths and for one-third of all economic damage, despite the fact that (thanks to development of information technology) the number of deaths per flood event has now been drastically decreased. Floods cause serious damages in both developing and developed countries, although their impacts are concentrated on relatively well defined areas. Between 1995 and 2015, floods affected 2.3 billion people and caused 157 thousand deaths. Because of the large population and the high population density of vulnerable areas, India, Bangladesh and China are the most affected countries.

There are at least 200-300 significant flood events per year globally. The effects are different in developed and developing regions: larger economic damage and fewer injuries occur in developed countries. For example, in 2002 the Central European flood caused more than $20 billion of damage and 55 deaths, while the flood in the southern part of Africa in the early 2000s caused $1 billion of damage, 929 deaths, and 733,000 refugees. The Yangtze River's flooding in 1998 killed 3000 and created fourteen million refugees, while the economic damages were $24 billion. In 2005, the flood on the Mississippi caused by Hurricane Katrina that flooded New Orleans caused $108 billion of damages and 1833 deaths.

Flood risk can also be affected by changes in climate conditions. Observations and climate models also indicate increasingly extreme precipitation distribution, thus flash floods are becoming more frequent, sometimes occurring in (and damaging) totally unexpected areas. At the end of April 2018, a flash flood caused ten deaths in the Negev desert (Israel), and at the same time in Algeria there were six victims. In April 2015, a flood caused by an extreme precipitation event in the Atacama, one of the driest deserts on Earth, affected nearly thirty thousand people and claimed twenty-nine lives in Copiapo, a town in Chile.[144] More examples could be provided, as many thematic web pages report about similar events on a daily-weekly basis.

It is obvious that flood events are highly dependent on weather events, but their impacts on society are greatly determined by human activities. By using previously flooded areas for farming or urbanization, human activities create the conditions for disaster. It is another issue that in many part of the world people who live in flood-prone areas have no other choice than to risk their lives and properties to ensure their daily livelihood.

6.1.8. Water conflicts and 'water wars'

As discussed before, the quantity of available freshwater resources is continuously decreasing, and this is increasingly a source of conflict. It can cause inter-sectorial conflict within a country or even conflicts between countries. It is interesting to note that the origin of the word 'rival' is also related to water problems – it refers to a person who extracts water from a river.

Typical examples of water-sharing problems within a country can be cited from the southwestern part of the US, where agriculture and the city of Las Vegas are required to share a scarce water supply. In certain areas of Oman, economic regulations control the distribution of water by setting up auctions for farmers. In the Valencia region, a long-established water court is operating to ensure the fair distribution of water use. In Australia, three federal states agreed on the division of the Murray-Darling water resources in 1989 after a fifteen-year period of negotiation, even allowing water trading. 'Forced' water distribution took place in a heavily water-deficient area of India where poorer farmers in Rajasthan could not irrigate because the wells in cities were over-exploited, resulting in groundwater depletion and a groundwater level so deep

[144] https://www.theatlantic.com/photo/2015/04/devastating-floods-hit-northern-chile/390024/

that farmers could no longer use it. More radical water-sharing examples can also be mentioned. In Mauritania, West Africa, the Moorish elite repealed the rights of predominantly black Africans living along the rivers to flood-based farming, leading to ethnic turmoil and the migration of about seventy thousand people. The real problem is related to rivers that flow through several countries. There are some ambitions to generally regulate the water distribution of such rivers, but because of fundamental conflicts of interest this has not been achieved so far. Thus, individual agreements between countries, forced treaties, and the military power that is also involved in the sharing of water resources between countries means there is a risk that wars will break out over water.

Countries on the upper reaches of river basins might think that they have the right to water resources, but this is strongly influenced by conventions and economic and military force. On the Nile, during the twentieth century, the military power of the main water user (the British Empire) and then of Egypt over the lower part of the river was much more significant than that of Ethiopia and Sudan. Thus, they forced the countries on whose territory most of the water resources are located into making very unequal agreements. Egypt got almost full rights to the dry season's water resources. At the same time as the Aswan dam was built, Egypt and Sudan agreed to allocate water resources in a ratio of 55.5 to 18.5 km^3. A subsequent conflict in the region was caused by the fact that the remaining eight countries along the Nile had been left out of the agreement, including Ethiopia, which is responsible for 80% of the river's discharge. In recent years, the conflict has intensified because of a large dam (and a 6,000 MW hydropower plant) on the Blue Nile that Ethiopia started to build to secure the water and energy needs of the rapidly growing population which threatens Egypt's ability to manage water use. In this respect, in November 2017, the President of Egypt stated: 'Water is a matter of life or death. … No one can touch Egypt's share of water'. Ethiopia's right to water is barely questionable. Egypt wants to keep the previously enforced situation. But who will dispense justice here? We can only hope that the solution will not involve weapons. In June 2018, the political leader of the two countries concluded a conceptual agreement, so it may be hoped that the conflict will be resolved peacefully.

If a militarily stronger country is located on the upper section of a river, it can force an agreement about water use more easily. In the case of the Tigris and Euphrates rivers, after the war in Iraq in 2003 Turkey was in a better position because of the weakening of Iraq on the lower section of the river.

A similar water conflict between countries with unequal power status is emerging along the Mekong River. The 15,000 MW hydroelectric power station that is needed for China's economic development is fundamentally changing the economy of the five countries on the lower section of the river. In Vietnam's delta region, the world's second largest freshwater fishing area may become endangered. Moreover, as countries along the lower section of the river are also planning power plants, it is supposed that the river will become an artificial system managed according to the demands of energy production and water transport. According to ecologists, in such a situation fishing-related losses will be greater than the profits caused by energy production.

In the early 2000s, there were two hundred and sixty-three major cross-border catchment areas around the world, nineteen of which were shared by at least five countries (the greatest number of countries share the Danube basin; in total, eighteen). Over the last half century, nearly two thousand cross-border 'events' (involving co-operation or conflict) have occurred in these river basins, seven of which have ended in violence, while in more than five hundred cases difficulties arose. Approximately 150-160 agreements have already been signed, but this does not guarantee a carefree solution.

The Palestinian-Israeli conflict, which is regularly reported on in daily news, is also strongly related to water scarcity. In Israel, the Palestinians' use of groundwater was strictly limited in 1967, although natural water courses are also of great importance in the dry climate. Before the war in 1967 Syria had already attempted to divert a branch of the Jordan River (Banias), while Jordan planned to build a dam on another river (the Jarmuk). After the war, the Golan plateau gained not only military significance, but also a role in controlling water interventions. In 1994, Israel agreed with Jordan about the sharing of water resources, and in 1995 an agreement was reached about Palestinian water rights, but this area is still considered a conflict zone with the potential for water war.

The Earth's water conflict map[145] shows a number of direct manifestations of this. Water can be a dangerous weapon if you want to use it as such. This was demonstrated in the summer of 1938 by the Sino-Japanese War, in which China tried to stop Japanese forces through the destruction of flood-controlling dikes on the Yellow River with a view to flooding areas threatened by the Japanese army. The result was 21,000 km^2 of flooded area, four million evacuated people, and eight hundred thousand deaths (due to the flooding and its consequences). With similar methods, ISIS attempted to defend itself east of Aleppo, Syria in 2017 (see the Water Conflict Map). In 1974, Iraq threatened to bomb a dam in Syria, alleging that the dam had reduced the flow of Euphrates River water to Iraq. However, in water-independent problems 'the weapon of water can also be used'. In India, the Munak canal, which supplies New Dehli with three-fifths of its freshwater, was shut down due to the economic protests of farmers in 2016. Sabotage of a canal left more than ten million people in India's capital, Delhi, without water. The Indian Army intervened to reopen the Munak canal,

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[145] http://www2.worldwater.org/conflict/map/

killing at least eighteen people and injuring two hundred. These examples demonstrate that there is already serious fighting for water, although battles are still small. However, the ever-decreasing availability of water resources already indicates its role in future power politics, and the irrational 'solutions' that may occur through despair and helplessness.

6.2. Environmental problems with the world's seas

Some 70.8% (361 million km^2) of the Earth's surface is covered by oceans and seas, which comprise approximately 97.5% (1.332 billion km^3) of global water resources. For the last century, global processes in the seas have been shaped by natural factors. Though humanity has been using it for several millennia (mostly coastal waters), fishing and shipping (wind-based) did not have a significant effect on these waters. However, due to the rapid economic development following the Second World War and the growing population, the seas have now suffered serious environmental damage. The effects of atmospheric changes (melting arctic areas, sea-level rise, acidification of the sea, coral destruction) have already been described in previous chapters. Moreover, there are two serious and likely future problems that are directly related to the activities of humans.

6.2.1. Overfishing

Marine fishing provides an important food source for humanity. Previously, the only limiting factor for fishing was the number and size of fishing nets, but by the middle of the 1990s fishing had reached the upper limit of sustainable production (and even overtaken this in some areas). In 1950, the amount of fish caught was only twenty-one million tonnes, but it had exceeded ninety million tonnes by the 1990s, approaching the FAO forecast in the 1970s that it could reach as much as one hundred million tonnes. In the 1950s and 1960s, fish capture increased spectacularly thanks to growing and increasingly well-equipped fishing fleets. Fishing at this time depended no longer on luck, but was determined by technical development: it was possible to capture specific species that swim in schools. After this spectacular growth, the increase in fish production slowed down and even decreased in the 1970s and stagnated in the 1990s at about 90-95 million t/year (Fig. 6.28) while remarkable problems have since occurred. Between 1950 and 2006, the size of fishing areas has increased tenfold, now reaching one hundred million km^2 and affecting the wildlife in at least one-third of the world's seas (Fig. 6.29). Today, fishing can be done in a sustainable manner on slightly over 10% of the world's seas, but on more than 30% of seas the signs of overfishing can be clearly detected (Fig. 6.30). Most fisheries are threatened by depletion, while signs of overfishing are becoming

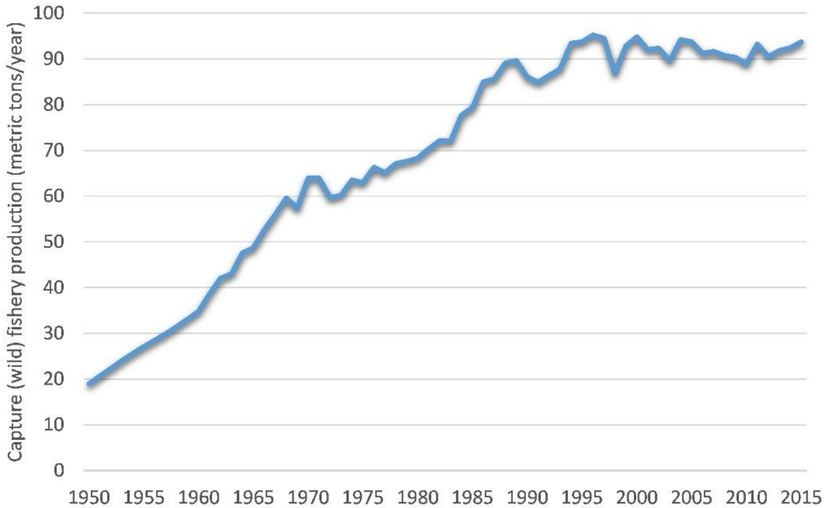

Fig. 6.28. Marine fish production between 1950 and 2015 (million tons) (Data source: FAO)

more and more obvious. Of the fifteen most significant production areas, eleven are declining, and the populations of two-thirds of the most significant fish species are also falling.

The magnitude of the problem is indicated by the fact that the catch of several fish species has had to be reduced or suspended. The process is well illustrated by the case of the North and Baltic Sea, where in the 1960s trawling by high-performance vessels became common, which swept the seas almost bare. Between 1960 and 1965, the catch doubled, but *the herring population was so drastically weakened that its capture had to be completely abandoned between 1977 and 1982* and the herring population can not be restored. Fishing for cod, whose population is also dependent on herring, is also threatened by the collapse. The anchovy fisheries of Peru have also changed dramatically. Between 1950 and 1970 production increased to 13.1 million tons (one-fifth of world production) from nearly nothing, then fell back to two million tonnes by 1974 and to 0.8 million tons by 1984. It then significantly increased to two-thirds of peak production by 1995. The most remarkable drop in the Atlantic cod catch occurred when the catch in Newfoundland dropped from the 1969 peak to a very low level by 1992 (Fig. 6.31) leaving many fishermen unemployed and requiring the Canadian government to provide economic aid. A fishing moratorium was originally planned for two years, but fourteen years later it still had to be maintained. Moreover, the capture of West Atlantic tuna decreased by 80% between 1970 and 1993. In view of the problems, the Marine Stewardship Council was set up in 1996 to promote sustainable fisheries.

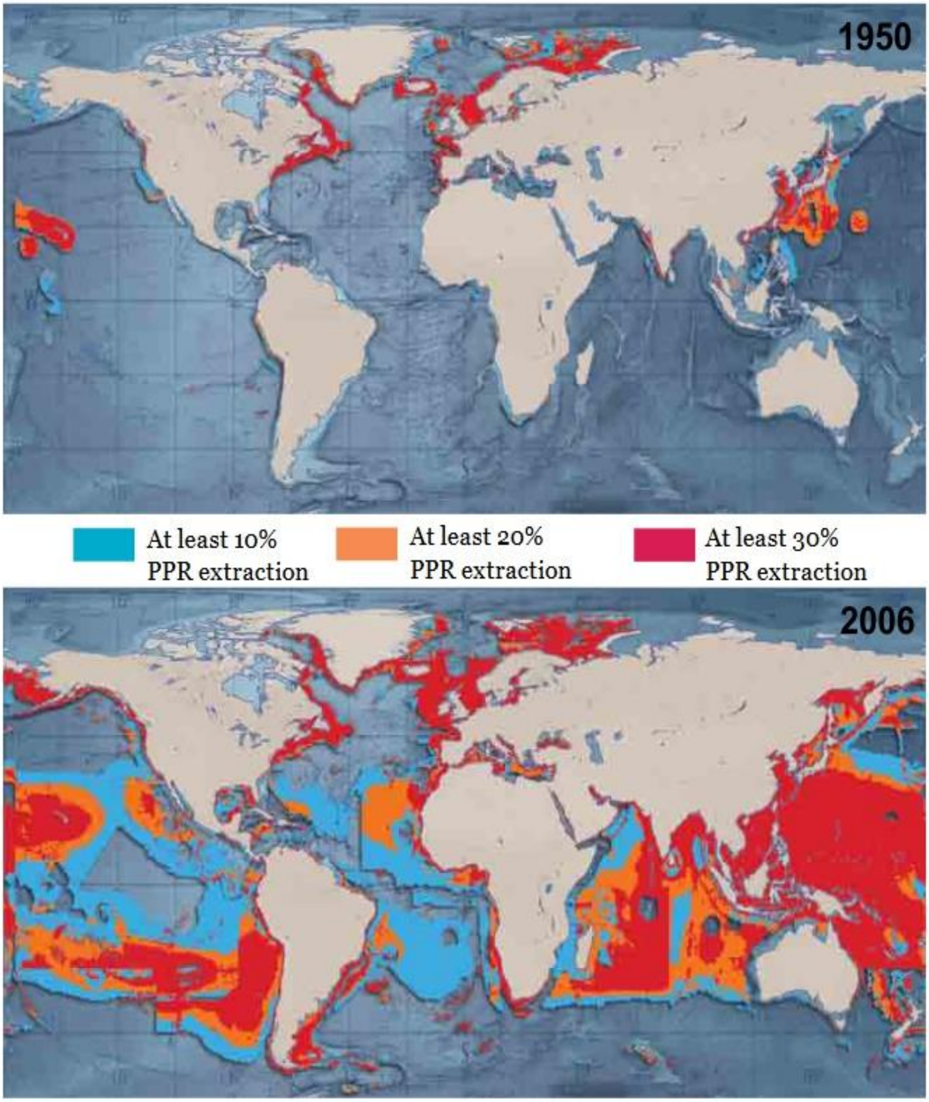

Fig. 6.29. The expansion and impact of world fishing fleets in 1950 and 2006 (Source: WWF[146])

[146] The figure is available on Page 85: http://d2ouvy59p0dg6k.cloudfront.net/downloads/lpr_living_planet_report_2012.pdf Primary production required (PPR): this estimates how much primary production is needed to replace the biomass of fishery landings removed from marine ecosystems.

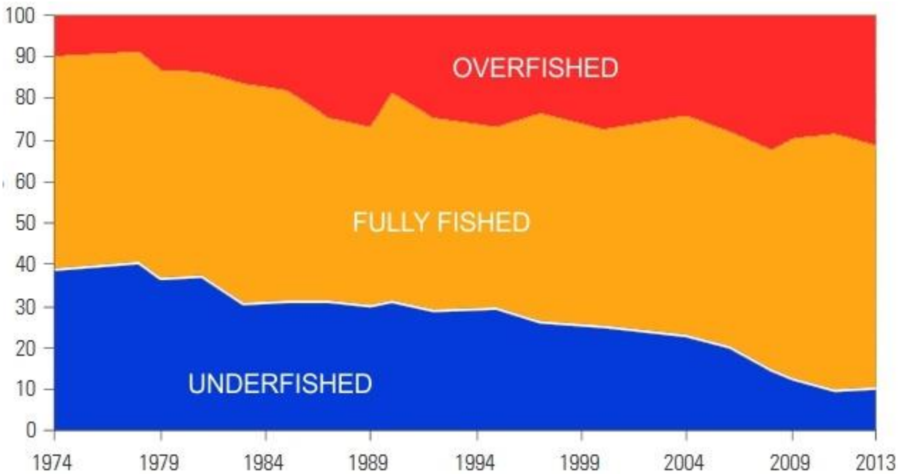

Fig. 6.30. Global trends in the state of world marine fish stocks (1974–2013) (Source: WWF[147])

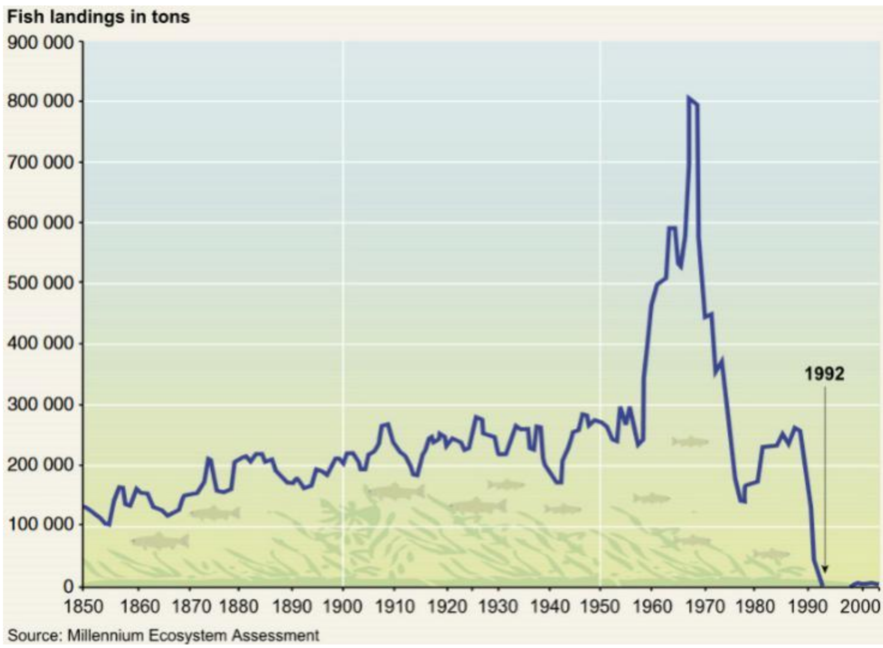

Fig. 6.31. Collapse of Atlantic Cod stocks off the east coast of Newfoundland (Source: Millennium Ecosystem Assessment[148])

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[147] Based on the figure on Page 55 at: http://wwf.panda.org/knowledge_hub/all_publications/lpr_2016/

[148] Available on Page 12: https://www.millenniumassessment.org/documents/document.356.aspx.pdf

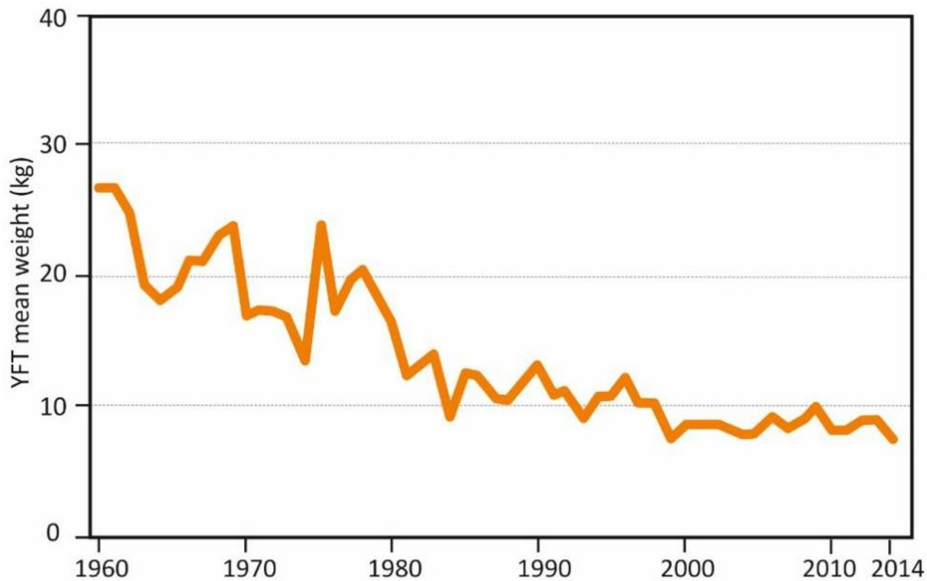

Fig. 6.32. Average weight of captured yellowfin tuna between 1960 and 2014 (Data source: ICCAT and FAO[149])

A typical change in marine fishing is that, after the radical decline in the population of some species, *previously less valuable species are now caught.* In this process, the share of pelagic species has increased, reaching half of the total capture in the mid-1990s. In the Central Atlantic area, the dominant tuna production of the 1960s was replaced by swordfish in the 1970s, while after another decade the sea trout was the species being caught. Near American coasts, some of the former fish species have been replaced by ray species or, more frequently, little catfish. Other striking signs of overfishing have also occurred, such as in the size of the fish that are captured. The average size of bait-captured swordfish has shrunk from 120 to 30 kg, while the average size of tuna has also decreased to less than half (Fig. 6.32) in a few decades, indicating a decrease in the size of the population. Even more spectacular is the reduction in the size and age of the red snapper in South Atlantic seas between 1962 and 2010: average length has decreased to half, and weight to one-twentieth, while the average age has decreased from eleven to two years.[150] It is worth mentioning, however, that in the Mexican Gulf after thirteen years red snapper

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[149] Based on http://www.iccat.int/Documents/Meetings/Docs/2008_SCRS_ENG.pdf (Page 25) and http://firms.fao.org/firms/resource/20/en

[150] http://www.pewtrusts.org/en/research-and-analysis/analysis/2011/05/09/overfishing-101-the-importance-of-rebuilding-our-fish-populations-without-delay

has been removed from the list of prohibited fish as it has significantly increased in number. According to Canadian researchers in 2003, the number of large predators in the world has decreased to one-tenth in fifty years. The volume of production can be increased or maintained only temporarily by reducing the quality of the fish that is captured, but the moratorium on fisheries has led to slow improvements in the fish populations in several fisheries. However, the North Atlantic (about 39% of the total area), and especially the Mediterranean and Black Sea (75-85% of the area) are significantly overfished.

A long list of examples could be presented to show that fishing has reached the limits of sustainability. In addition, there are other global issues with fishing. Ecological considerations have been neglected by fishermen for a long time, which has had serious consequences for fish fauna. A multitude of species have been exterminated or are near extinction. Several non-target species of specialized fisheries have also been meaninglessly devastated.

Problems affecting fisheries vary in different regions of the world depending on the levels of development. Countries with better technical competency and with greater economic power are able to maintain their activities for some time, and fleets that depart from overfished waters to the seas of poorer countries can skillfully exploit the technical differences and weaknesses in the control of fisheries. However, since 1996 the effectiveness of industrial fishing has also declined. In the last decades, various aquacultures have replaced the decreasing or stagnant performance of capture fishing. The amount of farmed fish and seafood from aquaculture grew almost fifteen times between 1980 and 2015, mostly in Southeastern Asia, including China.

An interesting issue is the hunting of whales, the largest animals on the planet. Although the international community has restricted their hunting through the International Whaling Commission (IWC) and has launched a moratorium on hunting, there are three countries (Japan, Norway and Iceland) which, despite common will, continue to destroy the whale population (most often claiming the need for ‘scientific research’).

6.2.2. Pollution of the world’s seas

Forty percent of the Earth’s population, about three billion people, live closer to the seas than 100km (of whom seven hundred million people live ten meters or more below sea level). This close relationship is manifested both in the exploitation of the seas (e.g. the role of fishing in food supply) and in water pollution. Untreated sewage that reaches the sea, nutrients and chemicals that runoff agricultural lands, and waste (mainly plastic) transported by influent due to the deficiencies in waste management have fundamentally altered coastal wildlife and later, marine ecosystems. I do not think there is a need to try to convince anyone about the severity of the problem: you may simply enter the following two words into a search engine: 'ocean', and 'waste'. If you select 'images' in the search bar, the result will be astonishing – and it will then be up to the reader to choose which images represent the problem most convincingly. Based on such images it is clear that the appearance of masses of plastic waste seems to be the biggest problem. In past years there has been almost no month or week without news about the presence and the harmful effects of plastic in the seas and oceans. This waste, which decomposes extremely slowly, has reached remote uninhabited islands, but also the deep sea (rubbish was found recently in the Mariana Trench).

Although there were some reports in the 1980s about large-scale floating garbage patches in the sea, the global problem of waste for ordinary people only became apparent at the end of 2006 when The New York Enquirer compiled an article about the 'Seven New Garbage Wonders of the World'. This drew attention to the huge island of garbage that is floating in the Pacific Ocean. Such a 'media impression' was needed to reach the public. But what was No. 1 in this ranking? It was the Eastern Garbage Patch, which was later named the Great Pacific Garbage Patch (GPGP). It was already more than twice as large as the state of Texas in 2007, and was located in the northern Pacific Ocean between California and Hawaii. The waste in the 'plastic island' originates from continents and has been transported and shaped by ocean waves for a long time, causing enormous problems to wildlife. The term 'island' is misleading, however, as this floating plastic mass cannot support a person's weight. It is also interesting that satellite remote sensing is not able to detect it, as the spectral properties of water are dominant.

Over the past few years, several expeditions have assessed its features and mapped its location, revealing other plastic waste islands too. According to our present knowledge, five large garbage patches related to great flow systems are known (Fig. 6.33), but there are also many smaller ones floating in the oceans. The plastic material is typically broken down into several centimetre- or even considerably smaller pieces due to sunlight. The Mega Expedition in 2015 mapped the GPGP in detail (using thirty ships and airplanes for surveying). On the basis of the survey we know that it has an area of 1.6 million km^2, but its real boundaries are difficult to determine as its density decreases towards the edges, and some pieces do not float on the surface but somewhat beneath it. The core part of the GPGP contains about eighty thousand tons of plastic. Their volume exceeds 100 kg/km^2 in the densest parts, but over large areas it is only 1-10 kg/km^2 (Fig. 6.34). Three-quarters of its weight consists of pieces larger than 5 cm, and many fishing nets are also found in it.

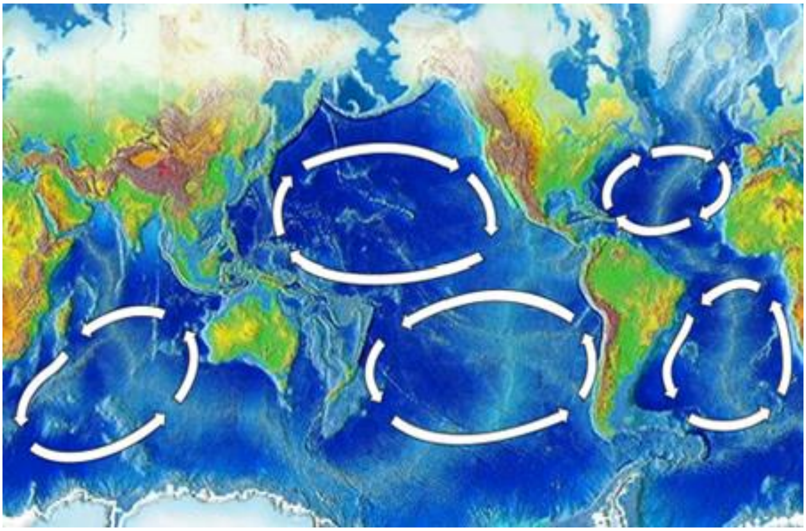

Fig. 6.33. The five offshore zones of plastic accumulation in the world's oceans (Source: NOAA).

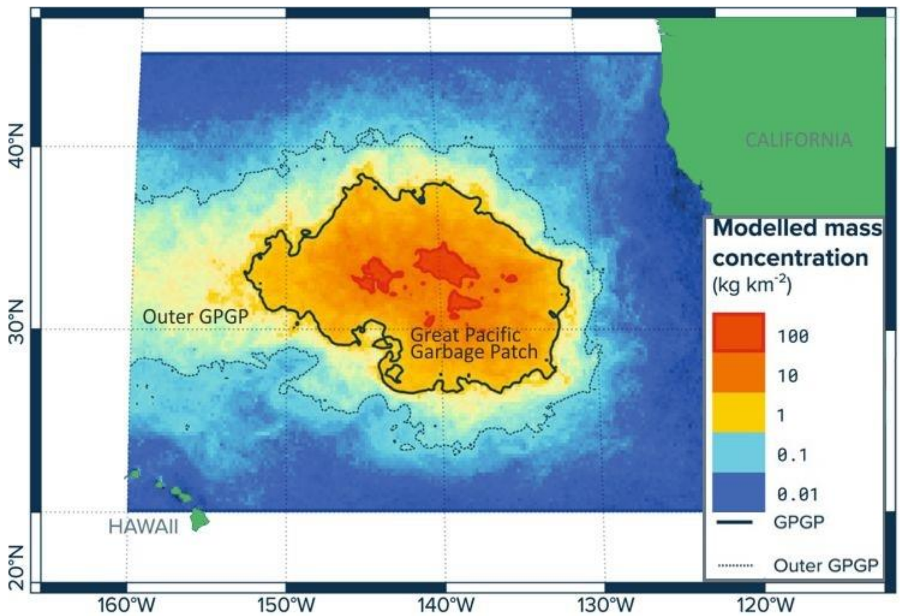

Fig. 6.34. Modelled mass concentration of waste in the eastern areas of the Great Pacific Garbage Patch according to a survey in 2015 (Source: Lebreton et al. 2018)[151]

[151] More details are available at: https://www.nature.com/articles/s41598-018-22939-w in Fig. 3.

According to estimates, at least eight million tonnes of plastic per year reach the sea, but some calculations lead to the claim that the amount is double this. At present, most of the plastic input into the oceans comes from Southestern Asian regions (Fig. 6.35). In Europe, the Danube River carries the greatest amount of plastic waste (530-1500 tons/year). In the Asian rivers, depending on the water regime, there are significant variations within the year: the Yangtze River carries up to seventy-six thousand tonnes of waste in the summer and two thousand five hundred tonnes in January; the Ganges River is characterized by 44.5 thousand tonnes in August, and less than 150 tonnes between December and March. Nowadays, five countries (China, Indonesia, the Philippines, Thailand and Vietnam) are responsible for 60% of all marine plastic waste. The weight of plastics in the oceans is currently estimated at 100-260 million tonnes, but by 2050 it may even exceed that of fish stocks (812 million tonnes).

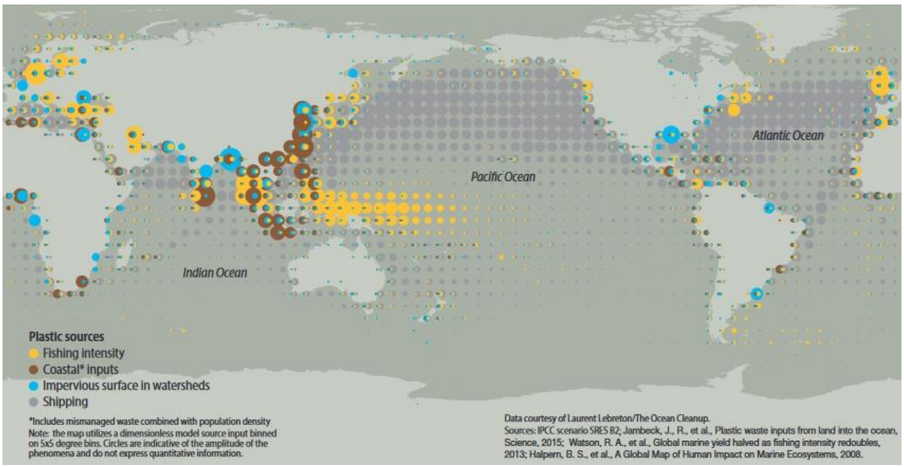

Fig. 6.35. Plastic input into the oceans (Source: UNEP 2016)

The number of these garbage islands is growing, but not only due to the ignorance of society. Occasionally, goods transported by ships that are lost during storms can contribute. There have already been thirty-three thousand pairs of NIKE baseball shoes, thirty-four thousand pairs of hockey gloves, and twenty-nine thousand yellow rubber ducks released into the ocean in this way. The main reason for the problem is rapidly growing plastic use and the deficiencies of waste utilization. A lot of waste also reaches the sea after major tsunamis. Due to the increasing pollution of global seawater, the UNEP published a report[152] on the problem of marine litter in 2016.

[152] https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/11/original/MarineLitterVG.pdf?1488455779

As a result of nutrient inflow from land surfaces, 'dead zones' are formed for a few months in many areas of the world's seas. The main cause is nitrogen contamination associated with fertilizer use. From the often over-fertilized soil, nitrogen is transported into rivers, and thence into seas and oceans (about one hundred and sixty million tonnes per year reaches the sea), where it induces algal bloom. When the algae die and sink to the seabed, they begin to decompose and reduce the oxygen content of the water. Death zones are formed where the concentration of dissolved oxygen is below 2 mg/l, thus they become real fish and plant cemeteries. The extension of the death zones also depends on weather conditions: they are formed in warmer summer periods and may last until mid-autumn.[153] A summary volume by UNEP in 2003 raised the issue of the rapid growth in the number of marine death zones which are endangering the food supply of a hundred million people. By 2010, there were nearly five hundred such zones, and their total area was estimated at 245,000 km^2 globally. The largest known death zones can even reach several ten thousand km^2 in extent. Such larger ones are mainly developed in the inland seas of Europe, and along the shores of North America and Southeast Asia. The largest ones have occurred in the Black Sea, but others were also reported in the Baltic Sea, the Adriatic Sea, the Mississippi Delta (the largest ever occurred in 2017, with a size of nearly 23,000 km^2), along the eastern shores of the United States, and at the mouths of the Yangtze and the Pearl Rivers.

A comprehensive piece of research published at the beginning of 2018 also revealed that oxygen-poor areas can be formed even further away from coasts if we consider not only surface waters (Fig. 6.36). Thus, the total size of dead zones may be much larger (up to several million km^2) than thought before. The oxygen-poor condition[154] of deeper waters, however, is not a consequence of such pollution but that of warming and acidifying seawater.

Beside the spectacular amount of floating waste on the surface of the water, ships and tankers (an estimated approximately 100 thousand, annually), which are a determinant part of growing world trade due to their delivery of raw materials and industrial products, have a serious effect on water quality. Apart from the oil and particulate matter they release into the water, they also have a significant effect on air pollution. According to an assessment from 2009, sixteen supertankers released as much sulphur dioxide (five thousand tonnes/year/ vessel) into the air as all the cars (about eight hundred million) on land at the

[153] Seasons vary according to the given hemisphere.

[154] Based on World Ocean Atlas 2009 data compiled by NOAA (https://www.nodc.noaa.gov/cgi-bin/OC5/WOA09F/woa09f.pl?parameter=o) it can be stated that oxygen-deficient areas can develop even to a depth of 150 m below the surface in certain parts of the ocean.

same time. However, the biggest form of environmental pollution related to marine transport involves tanker disasters. Until 2018 there had been ten tanker incidents involving a spill into the sea of more than 100,000 m^3 of crude oil. (Perhaps the most well-known one was the Exxon Valdez catastrophe, involving an oil spill of 'only’ forty-one thousand m^3).

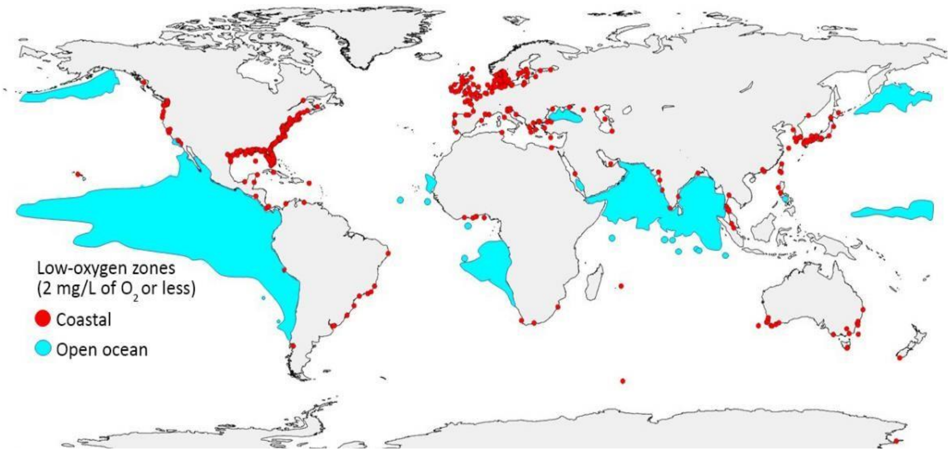

Fig. 6.36. Low and declining oxygen levels in the open ocean and coastal waters (Source: Global Ocean Oxygen Network, 2018[155])

Three major oil spills can be linked to crude oil production or a situation of war. Due to the Gulf War in 1991, a production failure (Deepwater Horizon) in Mexico Bay in 2010, and another production accident in 1979 (Ixtoc 1), at least 1.5 million m^3, about 780,000 m^3, and 530,000 m^3 of oil reached the sea, respectively. This contamination caused serious damage to the environment, and recovery took several years.

It is difficult to estimate the hazard of nuclear waste that has been dumped in the seas involving the by-products of civil (nuclear power plants) and military (e.g. the spent fuel cells of nuclear propulsion submarines) use. Such waste disposal is 'swept under the rug’. The major amount of the nearly 85,000 Tbqs of radioactive material is located near Novaja Zemlja (in the Soviet Union, formerly Russia), near the European shores of the Atlantic Ocean (mainly in Great Britain, Switzerland, and Belgium) and along the eastern coast of the USA. Due to the documentary films of Greenpeace, publicity played a decisive role in eliminating this bad practice. Unfortunately, some of the nuclear waste from the Fukushima Nuclear Power Plant accident also entered the sea.

[155] The map from the Global Ocean Oxygen Network (GO_2ON) summarizes surface and deep-water dead zone datasets. The figure below takes account of these data for depths of up to 300 meters. Data from World Ocean Atlas 2013 and provided by Diaz, R. J.

It is difficult to estimate the damage to wildlife due to the pollution of seawater. It is known that more than a million birds and hundreds of thousands of mammals (e.g. seals, and dolphins) die each year because they consume indigestible food-like waste (e.g. colored lighters, toothbrushes, and plastic bottle caps) or become entangled in a mass of waste. Shocking images of dead or distorted animals are available on the web. What is less known, however, is the fact that micro-nutrients and toxic compounds are entering the food chain. According to a study published early in 2018, in ice samples collected from the northern polar area 12,000 microplastic particles per litre (up to 11 µm in size) were detected in previous years. Forty-four percent of seabirds and one-fifth of cetaceans live with (bigger) pieces of plastic in their bodies,[156] but turtles and fish contain more plastic than was previously thought. Over the last 1-2 years, several studies have revealed that a large proportion of the fish in the sea consume a huge amount of microplastic particles, thus this material endangers not only aquatic but also human life.

7. Deforestation: a global problem

Human activity has played a role in the extinction of countless species, but one of the most spectacular changes has been caused by the destruction of the world's natural forests. About 8000-10,000 years ago, about 62.2 million km^2 of land was covered by natural forests, close to 42% of all land area (if the ice sheets of Antarctica and Greenland are not counted, around 46%). By 2015, this amount had decreased below 40 million km^2, [157] with significant regional differences in

[156] In April 2018, twenty-nine kg of plastic waste was found in the remains of a young cachalot that died along the Spanish coast.

[157] Previously, a much larger decrease was identified (e.g. in the mid-1990s, a figure of 33.4 million km^2 was published), but the FAO provided a new definition of forests in 2000. Currently, forests are considered those areas where there is 'land spanning more than 0.5 hectares with trees higher than five meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. This does not include land that is predominantly under agricultural or urban land use'. According to this calculation, smaller and sparser stands can also be regarded as forests, although this has increased the extent of forests by 20% (!). (This fact should be taken into consideration when evaluating time-series studies.) But statistics from the FAO based on country reports are not always coherent either. Except for consideration of the above issues, for this book FAO summaries available at http://www.fao.org/forest-resources-assessment/past-assessments are considered the primary source.

terms of consequences (Fig. 7.1). The decrease in the extent of forests was largest on three continents (Asia, Africa, and Europe), thus the share of intact forest ecosystems in these areas is now less than 8%. This figure, however, is misleading since almost all natural forests (now 0.3%) have disappeared in Europe. This latter fact is concealed by knowing that, for accounting purposes, Europe contains the entire territory of Russia.[158]

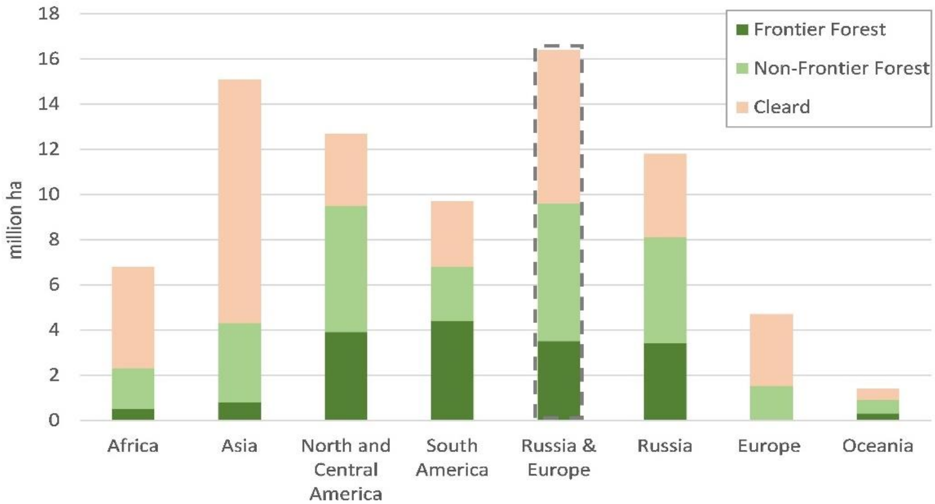

Fig. 7.1. Natural forests on all continents (Source: data from FAO 2015 and Bryant et al., 1997)

The present spatial distribution of forests shows (Fig. 7.2) that it is tropical and subtropical forests that have been felled to the greatest extent, and there has been little attempt to replace them. The first extensive deforestation occurred in the Mediterranean region 2-3,000 years ago. Two hundred years ago, the process accelerated in some parts of Europe and China, and the same was observed in eastern parts of North America one hundred years ago. In the past fifty years, significant changes have occurred in the remaining areas. In many developing countries, foreign trade is responsible for a large share of wood exports, thus these countries can not afford to neglect this, even if they are aware of its adverse consequences.

[158] Calculation of the forest areas of Russia compared to those of Europe may be misleading for the reader, mainly because the situation is often not correctly reported. About three-quarters of Russia's territory and most of its forest areas are located in Asia. The statistical practice of considering Russia's forests to be European ones can lead to the claim that the entire territory of Europe and its forest area are approximately 'the same size' (about 10 million km^2). For this reason, data for Europe and Russia are also presented separately in Fig. 7.1.

In many cases, exporting is only a temporary strategy, as illustrated by the case of several countries. Former exporters such as Thailand and the Philippines became importers in the early 1990s, and the wood production of Ivory Coast and Ghana also decreased spectacularly in the mid-1990s. A number of countries with a higher proportion of forest areas promise that they will not reduce the extent of their forests below a certain extent – but this is likely to continue until they will reach that value. This is why the rate of forest decrease has been significant even in past decades in places where resources did not seem to be limited.

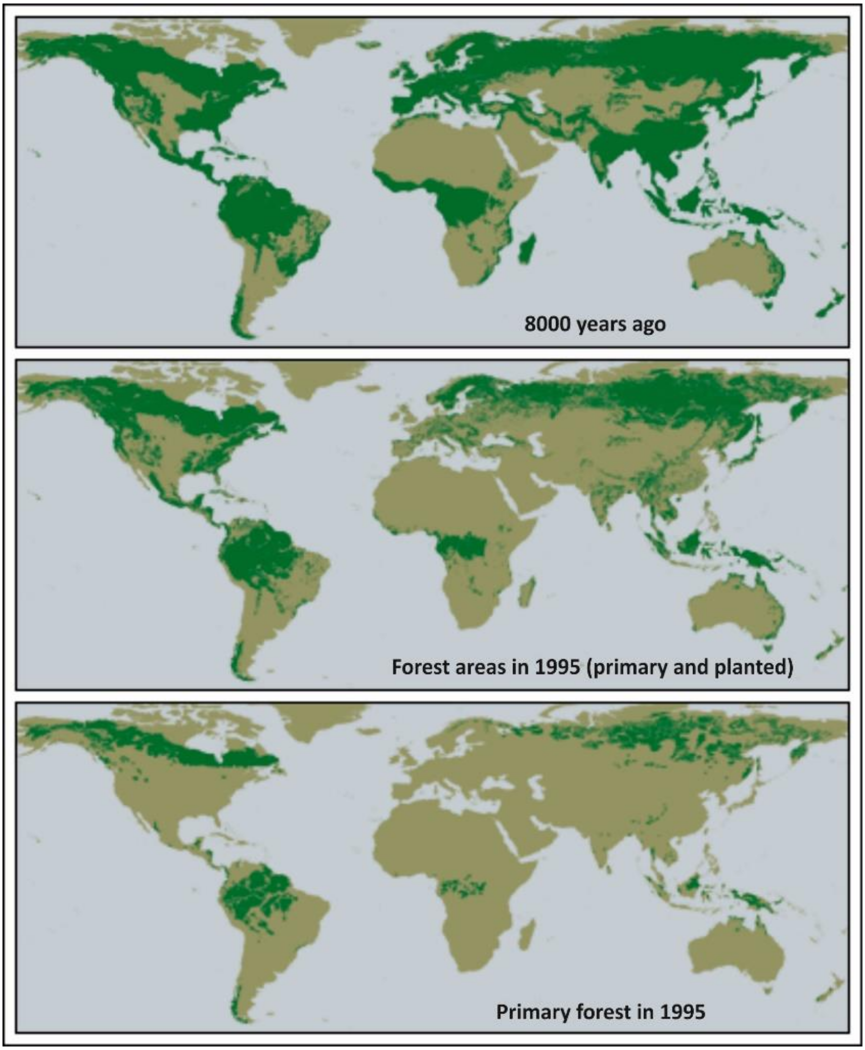

Fig. 7.2. Forest areas in the past and nowadays
(Source: based on WRI Bryant et al. 1997)

The global decline in forest areas around the world accelerated after the 1960s, reaching a peak in the 1980s. There were two main reasons for this: one was rapid population growth, and the other was rapid growth in world oil prices (from the mid-1970s onwards). Deforestation continued in past decades, although to a slightly lesser degree (Table 7.1), while afforestation also increased, mainly due to the role of China (Table 7.2). The largest decline in forest areas is occurring in Brazil, albeit the speed is slightly decreasing (between 2010 and 2015 the rate was 984 thousand ha/year, one-third of the rate ten years ago). Deforestation in Indonesia is second in terms of extent but the rate is also declining: the extent of destruction has more than halved in ten years. There has been a significant increase in forest decline in Myanmar, Tanzania, Bolivia, and Argentina. The greatest afforestation takes place in China, although the rate of this has more than halved over the past ten years (4058 thousand ha/year between 2000 and 2005, 1542 thousand ha/year between 2010 and 2015). It is an important change that the USA and Russia, both with large stands of forest, are now among the top afforesting countries, as is India (which has significantly reduced its forest areas) while many countries in Europe are seeking to replace forests that have been destroyed since the earlier phase of intense industrialization.

Considering the changes, four countries (Russia, Brazil, Canada and the USA) now share nearly half of the world's forests (Fig. 7.3) and three countries (Russia, Canada, and Brazil) have two-thirds of all natural forests: Two countries (Brazil and Indonesia) are responsible for about 60% of the decrease in forest area over the past 25 years.

Table 7.1. Changes in global forest areas (1970–2015) (using FAO data)

Period	Deforestation (million ha/year)	Afforestation (million ha/year)	Area decline (million ha/year)	Rate of change (%)
1970-1980*			≈ 7,0	
1980-1990*			≈ 9,9	
1990-2000	10,9	3,6	7,3	-0,18
2000-2010	9,3	5,3	4,0	-0,10
2010-2015	6,5	3,2	3,3	-0,08

* Estimated values due to incomplete data supply and different methodologies.

Table 7.2. Top ten countries in terms of greatest annual net gain and net loss of forest area, (1990–2015) (using FAO data)

Greatest annual net loss		Greatest annual net gain	
Average net forest area change (thousand ha/year)			
Brazil	-2127	China	2047
Indonesia	-1101	USA	306
Nigeria	-410	India	270
Myanmar	-407	Russia	239
Tanzania	-394	Vietnam	216
Zimbabwe	-324	Spain	184
Bolivia	-321	France	102
D.R. Congo	-311	Chile	99
Argentina	-307	Thailand	96
Columbia	-237	Italy	68

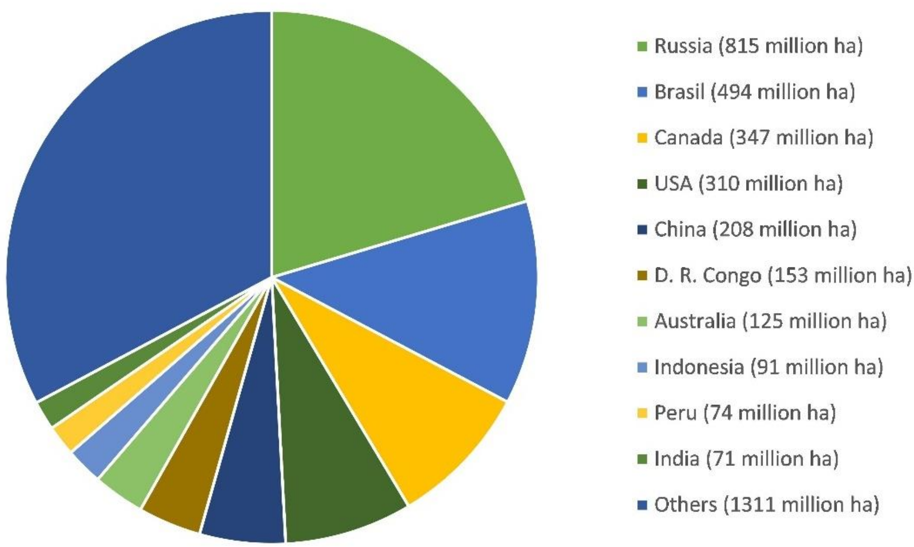

Fig. 7.3. Share of world forests between the ten countries with largest forest areas in 2015 (Data source: FAO 2015)

Forest area per capita is now around 0.6 hectares as a result of this continuous decline. In sixty-four countries of the world (where more than two billion people live), forested area does not reach 10%. Destruction is particularly significant in tropical forests, since the net loss has been around 3-4 million hectares in South America and Africa (Fig.7.4 and 7.5).

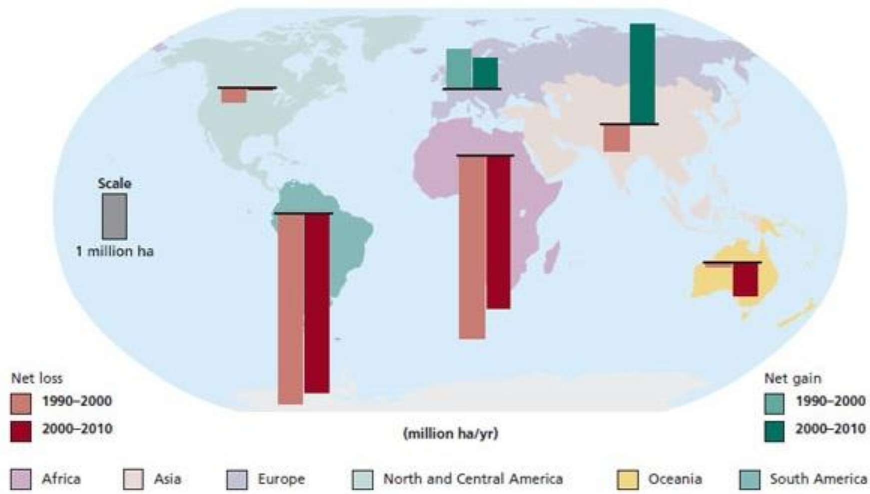

Fig. 7.4. Annual change in forest area by region (1990–2010) (Source: FAO 2010)

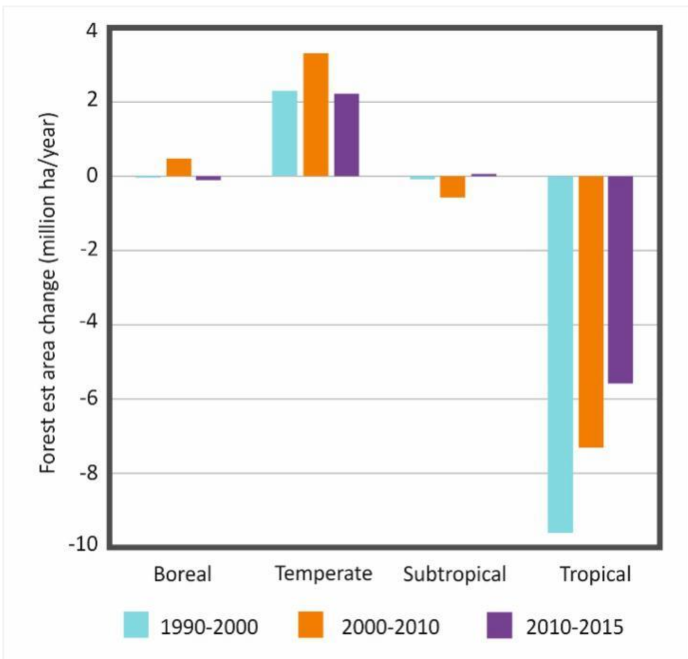

Fig. 7.5. Annual forest area net change by climatic domain (1990–2015) (Source: FAO 2015)

Why should we pay deforestation – among the numerous damaging human interventions – special attention? At least three of the many adverse effects of this practice may be mentioned.

a) A forest is not just a combination of trees but *a complex ecological system – tropical forests are the most species-rich terrestrial ecosystems.* Deforestation thus contributes to the destruction of many species, and ultimately (considering the selfish human perspective) contributes to the reduction of genetic resources available to humanity. It is, therefore, extremely problematic that great losses of natural forests have occurred in the past decades. According to data from 2015, *natural* forests have completely disappeared *from about 85 countries around the world*, and in some twenty-six countries they make up less than 5% of all land area – including Europe's most forested area, Finland (68.5% forested), where they make up a share of around 1%. This ecological problem is barely helped by the fact that the proportion of protected areas is increasing on all continents.

b) Forest stands play a very important role in the carbon cycle on Earth. A significant amount of CO_2 is incorporated into trees during their growth, therefore deforestation has a harmful effect on carbon dioxide emissions, and thus indirectly on the greenhouse effect, in two ways. On the one hand, deforestation (even if replaced by other vegetation) significantly reduces carbon sequestration, while on the other hand, carbon is later returned to the atmosphere. In many cases deforestation occurs through burning (it is not only the wood but the area that is obtained that is important) which happens almost immediately. The carbon released into the atmosphere due to forest burning can be easily detected by remote sensing methods. The carbon surplus in the atmosphere due to forest fires is estimated at around one billion tons annually. There were also periods when, due to changes in the price of hydrocarbons, forests were destroyed for firewood in the surroundings of the big cities of developing countries – to an increasing extent. According to an FAO report in 2017, there are still 2.4 billion people using wood as fuel to cook meals, sterilize drinking water, and heat their homes. Significant indirect effects can also be caused by the potential release of soil carbon stocks due to land-use changes. (The amount of carbon in a soil layer of up to 1 m in a tropical forest is approximately the same as that stored in vegetation, but more than five times higher in a boreal forest!).

The role of forests can also be highlighted because *they store more carbon, in different forms, than the entire amount that exists in the atmosphere.* The amount of carbon stored in the world's forests is estimated at 650 billion tonnes. As much as 44% of this is carbon in forest biomass, 11% in deadwood biomass and tree litter, and an additional 45% in soil. The transformation of forests can mobilize the carbon not stored in biomass, further increasing the CO_2 content of the atmosphere. According to research, the amount of CO_2 captured in forests has decreased almost twice as fast as the forest stock itself in the past fifteen years. Total carbon stocks are very different according to the continents (Fig.

7.6). According to estimates, 20% of the anthropogenic CO_2 emissions released into the atmosphere are due to deforestation and forest degradation, which is more than that attributable to transport (13%).

It should also be considered that trees (like other plants) play a key role not only in carbon sequestration but also in oxygen production. An 'average tree' produces 100 kg of oxygen a year, thus 7-8 trees can meet the annual oxygen demand of a single human. Amazonian rainforests are estimated to provide one-fifth of Earth's oxygen. With the excessive destruction of forests, this colourless, odourless, invisible, but essential element for life is endangered.

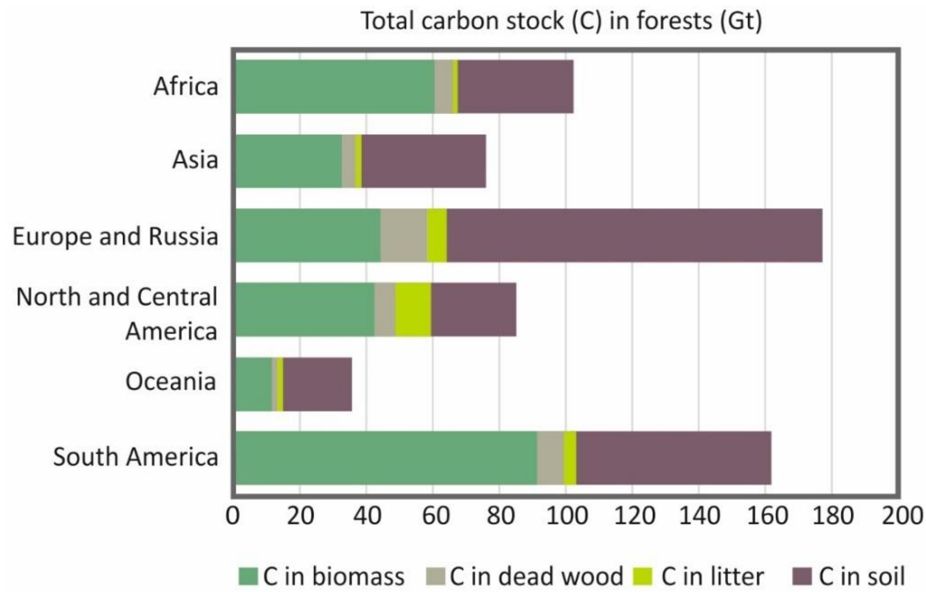

Fig. 7.6. Total carbon stocks in forests by region (2005) (Gt) (Source: FAO 2005)

(c) It causes serious environmental problems that, in the place of destroyed forests, agricultural areas are constructed that are rapidly eroded (5-10 years), especially in tropical areas. Eroded soil accumulates in ponds, reservoirs, and floodplains, causing considerable damage.

Further environmental problems related to deforestation should be mentioned. Forests absorb considerably more incoming radiation than the agricultural areas that replace them (e.g. tropical forests only reflect 15-20% of radiation), thus they modify Earth's radiation balance in a negative direction; *thus, deforestation indirectly increases the greenhouse effect* (this effect, however, is much less compared to the heating effect of greenhouse gases). Another, even less well known consequence is that, during forest fires, the heavy metals that have accumulated in trees can enter the atmosphere, which can have a significant impact on the environment under unfavourable conditions. Mercury contamination from such sources has been found in some areas (e.g. in Brazil). There are also serious health impacts related to the wood that is produced from tree-felling, since 93% of it is used as firewood in low-income countries (the figure is about 17% in developed countries), causing significant amounts of particulate pollution.

The threats caused by the decline in forest area were addressed as early as the 1972 Stockholm Conference, while in 1992 there was a separate document in Rio that dealt with the issue. Special attention was also paid to the problem in Kyoto in 1997 (see Chapter 16.2.2). Deforestation, however, is a both a politically and economically sensitive issue, and therefore rational scientific arguments only weakly influence practices. Forested areas are now almost only being reduced in economically less developed countries (Fig. 7.7), while those that exist in developed regions are protected by law and significant afforestation efforts are underway. This is why raising the problem of deforestation is perceived by developing countries as an attack against them. Their arguments are simple; the countries that seek to influence them and limit their activities have already destroyed their own forests. This statement is firmly supported by Figure 7.2.

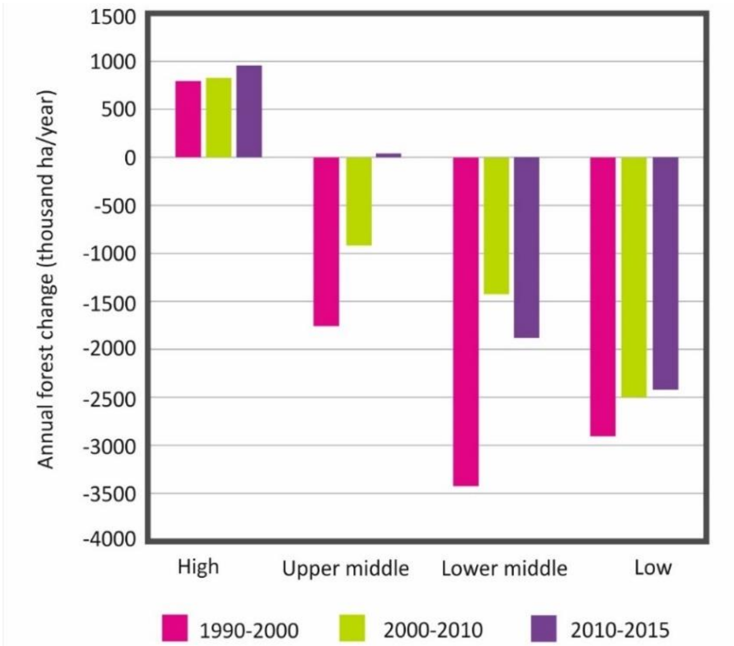

Fig. 7.7. Annual forest area changes by income category (1990–2015) (Source: FAO 2015)

It is a fact that wood is also an essential raw material these days, being an important renewable resource for humanity. One hectare of forest yields 110 m^3 of wood per year on average, although productivity depends significantly on geographical location (the two extremes values are 19 m^3 in North America and 189 m^3 in Middle Africa). Forest managers mainly use planted forests for wood production these days. Of course, in this case, the economic rationale is the main driver, but this can be harmonized with environmental considerations.

As a result of the attempt to improve on previous mistakes and to pay more attention to economic and human-environmental considerations, forest areas have been enlarged in developed countries over the past few decades, and sustainable forest management seems to be a reality – however, the low age of forest stands remains a problem.

8. The waste problem

Problems associated with waste treatment affect almost everybody on Earth. Generally, we meet with two extremes. In developed countries, waste management mostly focuses on selective collection, and the real problem is if a collection is delayed or canceled for some reason. In poorer regions, people meet with the everyday problem of disposing of waste, and sometimes supply themselves by rummaging through waste. Between the two extremes there are also many practical problems with waste handling. If you do not sufficiently perceive the problem, enter the word 'waste' into the search window on your web browser and select the 'images' menu item. Here are some facts to go along with the images: humanity produces 2.1 billion tonnes of waste annually, and if all this waste was loaded onto trucks the line would stretch around the world twenty-four times.

If we look for the reason for the increasing volume of waste, we find that the major factors are urbanization, industrial growth, consumer society, and changes in social habits. In urban areas, production and consumption are now significantly separated in space. With traditional farming, there was no need for packaging (nowadays, this is a major element of product marketability), organic household waste was composted and recycled within a short period of time, combustible materials were burnt in the stove, clothes and shoes were used by the next generation, eggshells were fed to chickens, and paper waste was collected by pupils – and numerous other examples can be mentioned. The result: there was hardly any waste, and if it was produced, it contained only a few non-degradable or toxic components. Nowadays, however, people are hardly interested in reusing waste – it is much easier to throw everything into the dustbin. Thus the amount of waste is increasing much more rapidly than the opportunities for its treatment or processing.

According to a relatively recent (2016) summary,[159] Denmark produces the highest amount of waste per capita (779 kg/capita/year), followed by Norway (751), New Zealand (731), the USA (735[160]), Israel (646), Germany (630), and Luxembourg (621). Consumer society makes us wasteful. The amount of waste we generate is important, but it also matters how this is managed. In developed countries, social demand and economic and technological opportunities, for example, have already made the 'zero waste' principle applicable to communal waste. (In this case the total amount of waste is much less important, as it is all used in some way.) In EU countries, the amount of waste per capita has hardly changed over the past decade (523 kg in 2016), but awareness about the need for its environmentally friendly disposal has significantly increased (recycling, incineration, and composting), while waste that goes to landfill now makes up less than one-quarter of all waste (Fig. 8.1). This data would be even more favourable without the inclusion of the recently joined EU member countries, where the role of landfills in waste disposal is still greater than 70%, and in some cases is the only solution for disposal (Fig. 8.2). Although change has also started in these countries, the slow speed of this shows that countries with a smaller GDP need a lot of time to adapt better waste management practices.

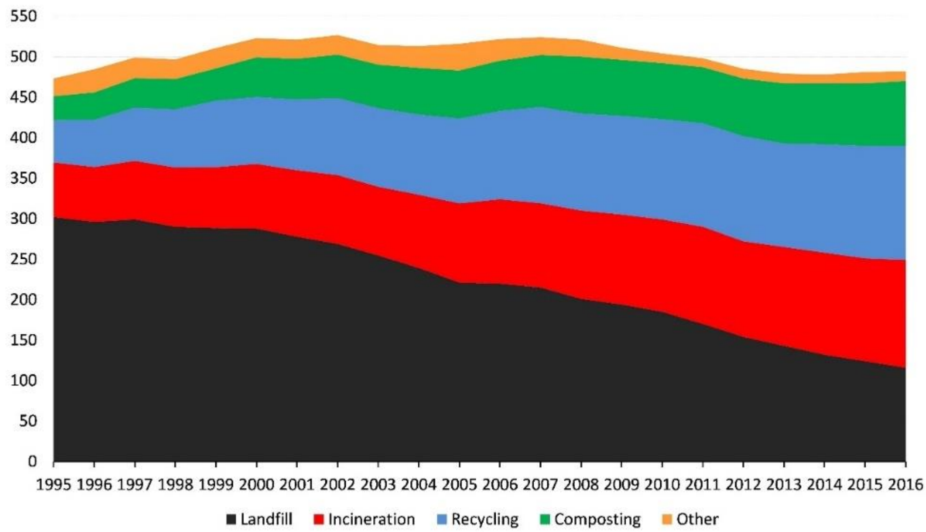

Fig. 8.1. Municipal waste treatment (EU-28) (kg per capita) (1995–2016) (Source: Eurostat[161])

[159] https://data.oecd.org/waste/municipal-waste.htm

[160] Data from 2015

[161] http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics

The waste problem is, of course, not new. The huge increase in waste since the 1960s has become an increasingly difficult challenge for economically developed, consumption-oriented societies. It is no coincidence, therefore, that even in the World Models waste appeared as a major global problem. In many versions of the Meadows' models, a catastrophic end is caused by environmental pollution (associated with waste) while other versions bank on the total use of waste due to shortages in raw materials.

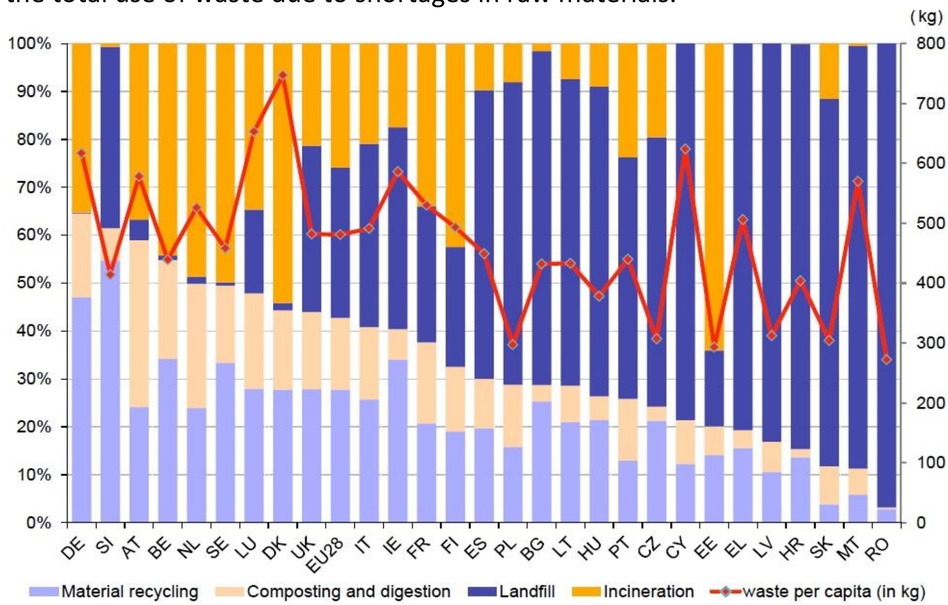

Fig. 8.2. Municipal waste treatment methods and waste per capita in the EU-28 (2013) (Source: EU[162])

The importance of the problem is shown by the fact that another report to the Club of Rome refers to this issue in its title (the Gabor–Colombo Report: Beyond the Age of Waste). Environmental problems related to waste can be classified into several types.

a) *Less space, more expensive disposal.* For a long time, depositing waste in landfills was common practice (unfortunately, this is still typical in many countries). This is typically carried out by filling in depressions around settlements, or using fertile production sites. The rapidly increasing amount of waste, however, required more and larger areas, and involved an increase in transportation and distribution costs. The big cities in the USA are good examples of these tendencies in the late 1980s: in Minneapolis, the residential solid waste fee was raised six times in a few years, the landfills filled up in Chicago, the waste from Philadelphia

[162] The figure is available at: https://libraryeuroparl.files.wordpress.com/2016/01/municipal_waste_treatment.png

was transported to Ohio. The famous New York waste disposal site, Fresh Kills, was the largest landfill site ever seen on Earth until its closure in 2001, and received over fourteen thousand tonnes of waste per day for more than fifty years. There is now a public park in its place, and the city's waste is transported elsewhere. The problems of unresolved waste disposal can be seen in the example of Naples as well. In 2008, government action was called for and rumors spread about the ‘waste business’ mafia. In past decades, waste disposal has become a critical issue for huge cities with millions of inhabitants in developing countries. A lack of land due to high population density poses problems in many places. However, there are places on Earth where the land surface is apparently worthless. For example, Kuwait disposes of some of its waste, such as unusable tires, in the desert (Fig. 8.3). The solution is almost symbolic: we tend to 'bury our heads in the sand' when confronted with the problem of waste (in line with the idiom related to dealing with the problem).

Fig. 8.3. Tire graveyard in the desert in Kuwait (Google Earth, 2018)

(b) Landfills pose numerous *environmental risks*. For a long time, landfills without environmental protection technology significantly polluted groundwater, occasional fires released dangerous gases into the air, and general 'mining’ of waste landfills (e.g. about ten thousand people live from picking rubbish in Mexico City) posed health risks. As a result of industrial development, more and more hazardous substances are deposited in landfills. One extreme example involved the death of a worker in a metal waste processing factory from radioactive material (and the illness of many others) in New Delhi in 2010. But chemicals and bacterial infections also endanger the health of the many thousands of people who rummage through waste dumps, but these effects are usually slower to occur. In the past years, however, several massive fatal accidents have resulted from slips on growing waste dumps. Just a few examples include the following: improperly designed and managed landfills resulted in a death toll of 31, 32, 115 and 17 in Manila in 2010, in Sri Lanka in January 2017, in Ethiopia in March 2017 and in Mozambique in February 2018, respectively. In these cases the rummaging people or poor settlers near the landfill lost their lives.[163] In May 2016, however, four firefighters who were extinguishing a fire in a landfill died in Ukraine due to its collapse. The increasing number of disasters clearly shows the deficiencies in the safety of waste disposal procedures.

Mining areas and industrial landfills also create problems. In Wales (Aberfan) an improperly created spoil heap caused the death of more than a hundred pupils in 1966, and the cyanide contamination of the Tisza River in 2000 is also linked to the 'waste disposal' practices of a mine.

(c) There are an increasing number of non-degradable and hazardous components in waste, but also compounds that are recyclable as raw materials. This fact plays a decisive role in treating waste as a raw material rather than as a mandatory disposal task in many countries. China has been the world's main waste importer for two decades. In 2016, forty-five million tonnes of metal, paper and plastic were purchased for approx. $ 18 billion ($ 16 million just from the USA). However, waste reuse in the major Chinese cities (like in Shanghai, which produces twenty-two thousand tons of waste per day) is lacking. As a result of the environmental problems with waste management, the previously mentioned controversy regarding reuse, and a 'greening program' launched in 2013, China stopped importing twenty-four kinds of waste (including plastic, paper, and textiles) at the beginning of 2018. This will cause problems in the short term, and lead to more environmentally friendly solutions in the long term, not only in China but also in the waste-exporting countries. It is a big question for the near future whether the other 'second largest' waste-handling countries (India, Vietnam, Thailand, and Malaysia) will try to fill the gap in waste processing, and if the largest exporters (USA, Canada, the UK, and Germany) will be able to take significant steps towards recycling in the short term.

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[163] News about these events is available at:
https://abcnews.go.com/International/story?id=83209&page=1,
http://www.bbc.com/news/world-asia-39607218,
http://www.africanews.com/2017/03/16/ethiopia-death-toll-in-addis-ababa-rubbish-dump-landslide-rises-to-115/,
https://www.independent.co.uk/news/world/africa/mozambique-rubbish-dump-collapse-kill-17-dead-heavy-rain-africa-a8217791.html

Over the past decades, opinions about thermal waste treatment (mostly known as incineration) have changed significantly. Waste incineration was occurring as early as 1874 (in Nottingham), but the practice spread only due to the decrease in landfill capacity. There were some uncertainties about the application of this practice due to the toxic gases that are released by the practice for a short period of time (during the stage of technological development), but waste incineration is now widespread in Western Europe, the US and Japan. At the end of the 1990s, however, an even more modern thermal process (called plasma pyrolysis) was developed and may represent the waste disposal and waste utilization method of the future. In Europe, Sweden has come to the fore in terms of energy utilization, since the waste imported from several countries has been incinerated in Swedish plants for many years.

d) The development of environmental policies in waste management. The developed countries who firstly met with the problem of waste were forced to take the necessary regulatory steps. An example of this is the waste management and recycling law in Oregon State (USA), which came into force in 1986 and is the first example of integrated waste management. It mandates for all settlements with over four thousand inhabitants a quantitative reduction in waste (applying the principle of prevention: making citizens understand that the cheapest solution is decreasing the amount of waste that is produced), recycling (following selective collection), the processing of materials that can not be directly reused, and energy use (incineration), thus only the residual components of waste may be deposited.

The diverse level of severity of environmental regulations in countries has also made the waste problem a global one. The high cost of hazardous waste management has ‘encouraged’ owners to look for cheaper options for disposal. This led to marine disposal and later practices disguised as ‘waste trade’.

The problem of garbage floating on the oceans has been described earlier in this book. The global nature of waste problems, on the other hand, is well illustrated by the fact that since 2000 regular initiatives have been organized to remove the garbage from Mount Everest. In the summer of 2008 China announced that it would ‘clean’ the Himalayas again and obliged mountaineers to take all their equipment and waste back after hiking. Some years ago, attention was also drawn to the problem of growing amounts of waste in Antarctica.

Plastics have become an indispensable part of our everyday lives in past decades because of their relative low cost and versatile applicability. Twenty times more plastic has been produced since 1960, but the amount has also almost doubled in the last two decades. Plastics are most widely used for packaging (almost 40% of all plastics are used for this purpose in Europe) and in the construction industry (20%). Plastics, however, are also dominant components of communal waste, not by mass but volume. Plastic bottles and bags are easily transported by water and wind due to their larger size and low weight, causing numerous environmental problems (as demonstrated in the section of this book about the world's seas). This is the reason why countries (or regions of countries) have introduced administrative regulations to restrict or prohibit their use. An almost total ban on plastic bags was introduced in Mauritania (because many animals died due to their consumption), Senegal, Ivory Coast, Mali, Ghana, Kenya, Ethiopia, Malawi, Mauritius, Rwanda, Zanzibar and Uganda – with very different restrictions and legal consequences (from fines, to several years of imprisonment). This example was followed by France and Romania in Europe, but in much reduced form.

e) The occurrence of large amounts of food in waste raises severe ethical issues. According to an FAO report in 2011, one-third of all food is wasted: sufficient to supply three billion people – while eight hundred million people are starving. The significance of the problem is shown by the fact that the British Prime Minister raised his voice against food waste in July 2008. According to a survey, 4.1 million tonnes of consumable food per year are wasted in the United Kingdom (to the value of about £10 billion), but an assessment at the beginning of 2017 claimed that the amount is approx. 7.3 million tonnes of food of a value of £13 billion. According to the *Food Wastage Report* of the FAO in 2013,[164] it is mostly vegetables and cereals (7.5 to 11%) that are thrown away in industrialized Asian countries (China, Japan, and South Korea). Food wastage per capita is largest in North America and Europe. The total carbon footprint of the food that is wasted is 3.3 Gt, which ranked using a country comparison would put food waste in third place (after China and the USA).

f) Hazardous waste poses serious problems throughout the world (due to its inflammable nature, reactivity, toxicity, and corrosivity). In developed countries, the utilization of hazardous substances and the disposal/destruction of residues that become obsolete during reuse are well regulated. In many countries, however, regulation is insufficient and dangerous materials, disposed prior to environmental protection activities, can pose a very serious risk. Detecting hazardous sites and eliminating contaminants would be in the interest of all countries, but this requires serious resources and, unfortunately, such practices are hidden in many areas. The Blacksmith Institute[165] has been gathering data about the most polluted areas[166] on Earth for more than a decade, and is working to eliminate the related threats through various programs.

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[164] The assessment is available at: http://www.fao.org/3/a-i3347e.pdf, its key findings can be found at: http://www.fao.org/save-food/resources/keyfindings/en/.
[165] http://www.pureearth.org/
[166] A report from 2016 is available at: http://www.worstpolluted.org/docs/WorldsWorst2016Spreads.pdf.

9. Limits on non-renewable natural resources

Rapid industrial development, coupled with rapid population growth (as already described), has been responsible for the uncontrolled exploitation of natural resources for a long time. The gap between the resources that are available, and those that are required (which accelerates their exhaustion) has become increasingly apparent since the 1960s. This is the reason that calculations have been made to predict how long these indispensable raw materials will serve the needs of humanity.

The Meadows model (described in Chapter 3) was the first to attempt to quantify this, and forecast the very rapid depletion of some raw materials. Considering the rapid economic growth of the 1970s, with the exponentially increasing utilization of resources, a 9-15-year depletion time was predicted for gold, silver and zinc; in the case of crude oil, natural gas and copper it was 20-22 years; aluminium 31 years; iron 91 years; and 111 years for coal. The estimate was that even in the case that 5-6 times more resources became available, depletion time would only be increased by 2-3 decades. At this time, mostly hydrocarbons and noble metals appeared to be the factors limiting the future economy. Based on the demand-supply relationship, it was not surprising that raw material price shocks occurred within a very short time.[167] This economic process fundamentally changed the rate of raw material use, and further price explosions have led to a constant decline in the rate of increase in consumption. Besides environmental reasons, the decrease in available resources has also triggered the uptake of recycling, while the issue of substitutability and the role of technological development has become increasingly important. It has now been demonstrated that the analysis of Meadows was inaccurate in this regard, but the problem still has to be taken seriously.

Humanity uses numerous non-renewable natural resources. This book does not try to take all of them into account in detail, but only some of the more important ones, or the ones that have been more focused on in the last decade, are discussed in this chapter.

9.1. Oil and the Hubbert curve

Humanity tends to believe in miracles and place its trust in science as regards the future. It does not want to accept that the Earth's resources are finite,

[167] The truth is that there were political reasons for the first oil crisis in 1974: Arabic oil-producing states wanted to force the US to withdraw their support for Israel.

and some of the resources we use may be exhausted within our lifetimes. The rate of our present life's vulnerable can be illustrated with the example of crude oil and other fossil fuels.

When M. K. Hubbert, a well-known geologist, predicted in 1956 based on a model that oil production in the contiguous United States would peak at around 1970, he found himself in the midst of a serious uproar. But, despite all the difficulties, professional and political pressures, he stayed true to his opinion which was proved true in practice within a decade and a half – the peak occurred in 1971. The Hubbert curve that he invented for oil was later considered to be widely applicable to non-renewable resources. But what did Hubbert figure out?

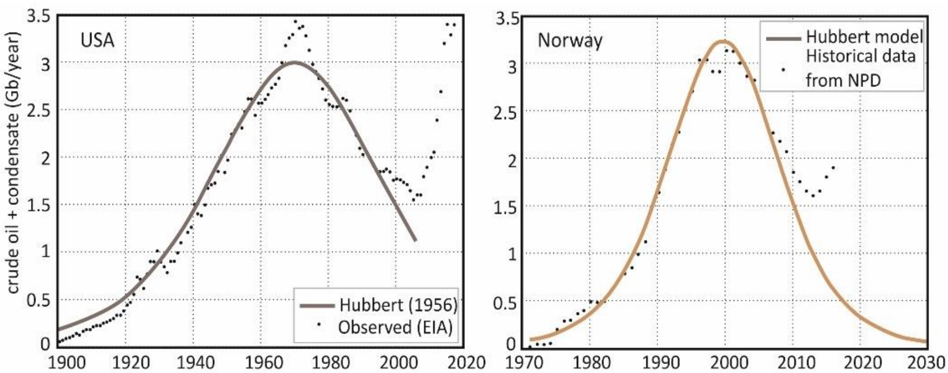

Fig. 9.1. Hubbert curves of oil production in the USA and Norway until 2017 (Source: IEA)

Based on his research experience and calculations, Hubbert found that the production of oil follows a bell-shaped curve. The production curve can be divided into increasing and decreasing phases. At the beginning of the phase of exploitation, if a valuable and widely-used resource appears on the market and available stocks freely meet growing demand, production grows exponentially as long as the increase in demand and production are brought into equilibrium (this is the inflection point during the phase of increase). After this, meeting demand is only possible by discovering and exploiting new extractable reserves, which is usually increasingly difficult and expensive to do. Thus, the former increase in production gradually decreases, and then stops (the 'Hubbert Point'). After that, production decreases. In the initial phase of descent, the rate of decline is slow, but it then becomes more intense and reaches a maximum at the inflection point. In the last stage, demand gradually decreases as the resource must be replaced by other resources due to its depletion. Finally, production declines to zero. Hubbert's findings were later generalized and applied to global oil production. The shape of the curve may change due to economic and geological differences, but its basic findings seemed to be generally applicable. Norway's oil may be a good example (Fig. 9.1). In the USA, nearly one hundred years passed between the beginning of production and its peak phase; in Norway this took only thirty years. (In the UK this time was even shorter: twenty-five years.)

Of course, the Hubbert curve for the oil production of individual countries cannot be extrapolated to the global situation without specific caveats, although the general logic may be relevant. In the early 2000s, many researchers and oil specialists (who had earlier had doubts about the global validity of the curve) tried to draw the attention of the world to the serious consequences of a potential global production decline. Believers in 'peak oil' think that an all-time peak in world oil production will soon occur. They have formed an international organization (ASPO[168]) and continuously publish their evaluations about the topic. The reason why oil industry professionals have formulated doubts about the longer-term future of oil while world oil production seems to have grown steadily was summed up by J. Leggett in his book.[169] The most important argument is that, although methods and exploration equipment have undergone remarkable development over the past half century, and demand for oil has also increased dynamically, newly discovered stocks are constantly decreasing. The discovery of new oil stocks peaked in 1965 and, since the beginning of the 1980s, discoveries have lagged behind annual production. At this time, it seemed that the major sites had already been explored decades ago, and deep sea discoveries had peaked. No-one expected a significant increase in oil extraction efficiency. (By the way, at that time there was a 2-3-decade difference between the findings of ASPO and the optimistic estimates at the time of the oil peak which assumed there were an additional two trillion barrels of oil yet to be discovered.) At the beginning of the 2000s, geologists became aware that the use of unconventional resources (oil shale, and oil sand) could be another way to expand oil stocks. Huge reserves of these unconventional resources are available mainly in Canada and Venezuela. However, according to preliminary experiences the extraction of these resources is not only costly but also causes significant environmental damage. In light of these new stocks, large oil companies now estimate we have at least another 4-5 decades until peak oil. However, if these unconventional stocks can not be economically extracted, the oil peak on a global scale is now near, as half of all available stocks have already been extracted.

Regarding perspectives about the next phase, numerous evaluations have been published. Although the author of this book does not intend to discuss the

[168] Association for the Study of Peak Oil

[169] J. Leggett 2005: *Half gone*.

details, it is quite clear that a series of manipulative economic and political decisions have determined the price and production of oil since 2005, not purely economic processes. From this point onwards, the rules of the Hubbert curve will be overcome by day-to-day practices.

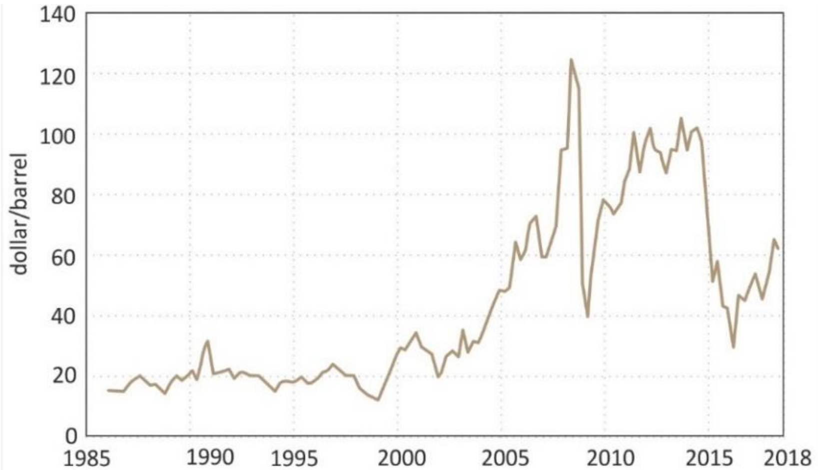

Fig. 9.2. Brent Crude Oil prices between 1986 and 2017
(Source: based on data from Bottazzi 2016 and EIA)

What is happening must start with changes in oil prices. At the beginning of the 2000s, there was a significant increase in the price of oil compared to previous periods. In the 1990s, the $ 20 per barrel price fell to $ 15 in 1999, while by the end of 2001 it was already over $ 30. By the end of 2002, it fell again to $ 20, but then the price of oil started increasing at an incredible rate. This increase may be explained by the declining stocks and rising demand until the beginning of 2005, but no sensible economic justification for the changes of the next three years can be found. Until the summer of 2008 (i.e. in the following three-and-a-half years), the price increased more than fourfold (the price of Brent Crude Oil reached $ 147.5 on July 11). Then, in a year, it fell below $ 40 for a short period, then between 2012 and 2015 the price rose to around $ 110 for a longer time. Again, by 2015 the price had significantly dropped to $ 50 (and even reached $ 35). At the time of writing of this book (June 2018) the price of oil was approaching $ 70 (Fig. 9.2). Such extreme price fluctuations in the past one-and-a-half decades cannot not be justified either by an increase in producer costs, declining supply, or by problems with freight transport. However, a significant role in these price fluctuations was played by a deliberate reduction in production aimed at changing prices, and the temporary or partial loss (because of the war situation in the Middle East) or exclusion (e.g. as part of international sanctions against Iran) of some producers. However, these moves were not always in sync with price changes.

The oil price shock in 2008 – the fact of which is hardly questionable – was driven by the profit-seeking of a relatively small group of the biggest producers. The changes in 2008-2009 remind us of a statement by Yamani Sheikh, a former Minister of Oil (Petroleum) and Mineral Resources of Saudi Arabia: 'The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil.'[170] But what did this incredible increase in prices result in? The high prices forced the economy in two important directions. On the one hand, it triggered technological developments (e.g. wind and solar energy) aimed at decreasing the role of oil in the energy supply, and on the other it also triggered the development of unconventional crude oil production technologies (oil sands, oil shale, and hydraulic fracturing), which were formerly out of scope because of their cost. The utilization of renewable energies has led to a decline in the market for oil, while new production processes have led to an increase in the supply side. The significant price increases have had clear effects on everyday life too in terms of energy saving, and decreasing consumption.[171] Perhaps the most striking sign of this effect was the decline in car traffic – though this was less than during the first 'price shock' of 1974. However, the greater involvement of renewable and environmentally friendly energies was not without difficulty. On the one hand, these sources cannot provide a continuous energy supply (due to the limitations on solar energy (e.g. at night-time) and also on wind energy (the wind doesn't always blow)), which requires reliable technical solutions in the long run that can be applied on a large scale. On the other hand, the significant drop in the price of renewables in 2009 caused economic and financial problems, and several developers went bankrupt. However, the oil price increase also created tremendous opportunities for unconventional hydrocarbon production. If you examine the annual trend of oil stocks over the past two decades, you will observe that for many years at the bottom of the Total Proved Reserves table were Canadian oil sands, and later, Venezuela (Orinoco Belt), which were included as potential stocks. The inclusion of these resources on the list of real stocks and the start of their exploitation – moreover, the spread of hydraulic fracturing (currently most developed in the USA[172]) – have created a new situation on the market. In both parts of the American continent, stocks and production have changed dramatically (Fig. 9.3)

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[170] See: https://www.economist.com/node/2155717

[171] The OECD countries responded to the price changes by reducing their consumption, as can be see here: http://www.energyeconomist.com/a6257783p/world/outlook/graphs/small/coecd.gif

[172] The success of this oil production technology depends on geological conditions. For example, the technology used successfully in the United States has not generated good results in Hungary – despite the presence of the stocks – due to the high temperature and pressure of reservoirs.

and the global distribution of stocks has also changed (Fig. 9.4). Recently, the most important factor in the development of oil prices has been growth in US oil production, as the USA, the largest crude-oil-producing country, is less and less dependent on imports: between 2005 and 2017 the volume of imports dropped to a third of the former level (Fig. 9.5). It can be seen, however, that China's imports have doubled in the same period, thus of course it is trying to use all possible options to increase its production. Although there was a period when the drop of oil prices led to a drop in the more expensive US production, but the potential involvement of unconventional resources in production has now become a serious limitation on unrealistic world market prices.

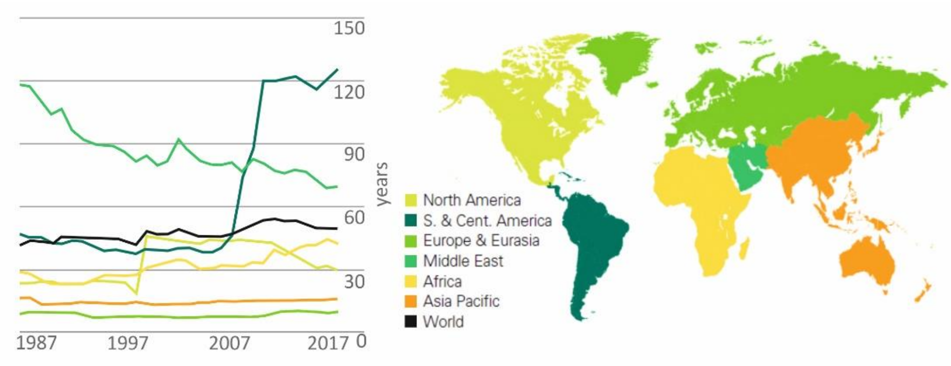

Fig. 9.3. Availability of oil stocks by year[173] in the main regions around the world between 1986 and 2016

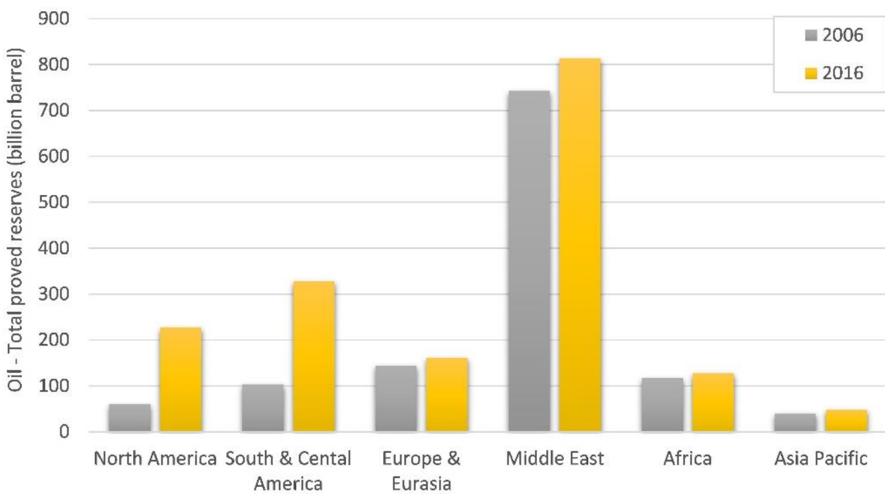

Fig. 9.4. Proved oil reserves in the main regions around the world between 2006 and 2016 (Billion barrels) (Source: BP 2017)

[173] Ratio of stocks to demand

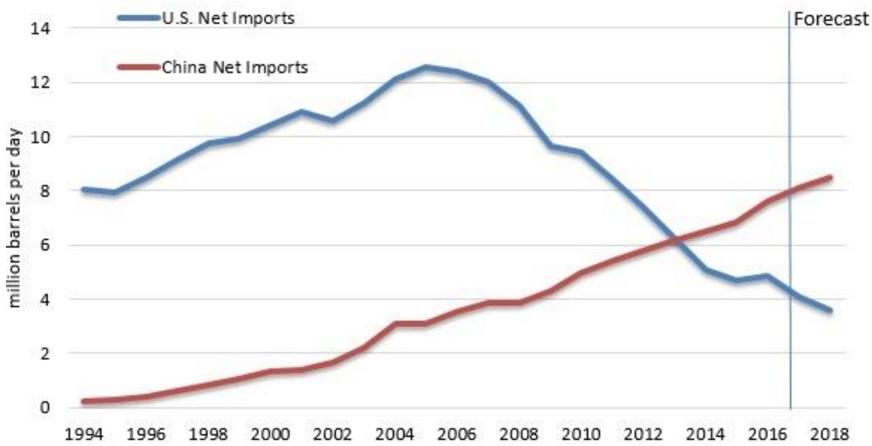

Fig. 9.5. Oil imports of the USA and China between 1994 and 2017 (Stanley et al. 2017)

Although the potential of the new resources seems to be favourable to humanity, they are associated with numerous unfavourable global consequences. If oil is still available, it will continue to contribute to the increase in atmospheric greenhouse gases. The extraction of oil sand and Venezuelan heavy crude oil[174] results (or may result) in significant environmental pollution. The new resources also reduce public awareness of the issue, as people continue to perceive that stocks are unlimited. However, in my opinion the previously discussed logical arguments of ASPO are correct; the only difference is that the Hubbert curve has to be applied to larger stocks. ASPO's most important finding was that for more than two decades, humanity had used more oil than was newly discovered. Using a more understandable analogy, if we put a dozen boxes of milk into the fridge and drink more than we buy each week, the fridge will be empty sooner or later. If we buy a larger quantity again, this does not mean that it will be available for unlimited use later. New discoveries of the last one-and-a-half decades are only slightly delaying the depletion of crude oil, but stocks will be depleted. At today's consumption level, the availability of reserves is half a century (Fig. 9.3). It is also likely that new and significant stocks will be discovered in the future. The reduction of Arctic ice cover makes the extraction of stocks under the Arctic seas possible. (Regarding this, Russia seems to be in the best position.) Perhaps it is no coincidence that ASPO has also abandoned its former main focus of activity, although several regional units are still conducting analyses today.

[174] Based on some estimates, the amount of extreme heavy oil discovered on the Orinoco River Delta can be equal to the world's light oil reserves in the future. However, its exploitation by the country is a question of the future.

Nowadays it seems that the Hubbert curve is valid for many countries, but for world production it will only be possible to construct it in a few decades' time (with approximate knowledge of the total stock). According to present data, the non-conventional reserves in the USA will be able to support production growth for more than a decade (if world market prices justify such continuous production). An important issue for the future is the replacement rate of oil with renewable energy.

Several signs indicate that the 'age of carefree oil' will not last forever. The extraction of conventional oil reserves seems to have reached its peak (Fig. 9.6). In about sixty oil-producing countries the production rate has been declining for a decade, and nowadays two-thirds of the largest forty-two producers have reached or are close to the peak of production. In several cases, there is suspicion that real reserves have been overestimated, which would have the greatest impact in Saudi Arabia.[175] The graph included in BP's Statistical Reviews publication about changes in oil reserves may also be misleading, as it greatly enlarges changes in inventory due to new discoveries (Fig. 9.7).

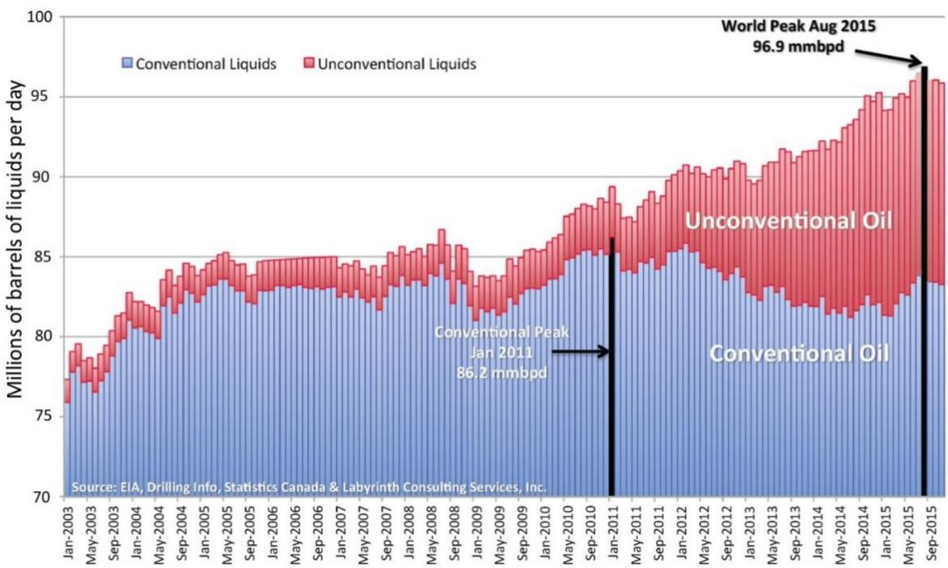

Fig. 9.6. Conventional and non-conventional oil production between 2003 and 2015 (Source: Heinberg 2018)

[175] See: https://www.theguardian.com/business/2011/feb/08/saudi-oil-reserves-overstated-wikileaks

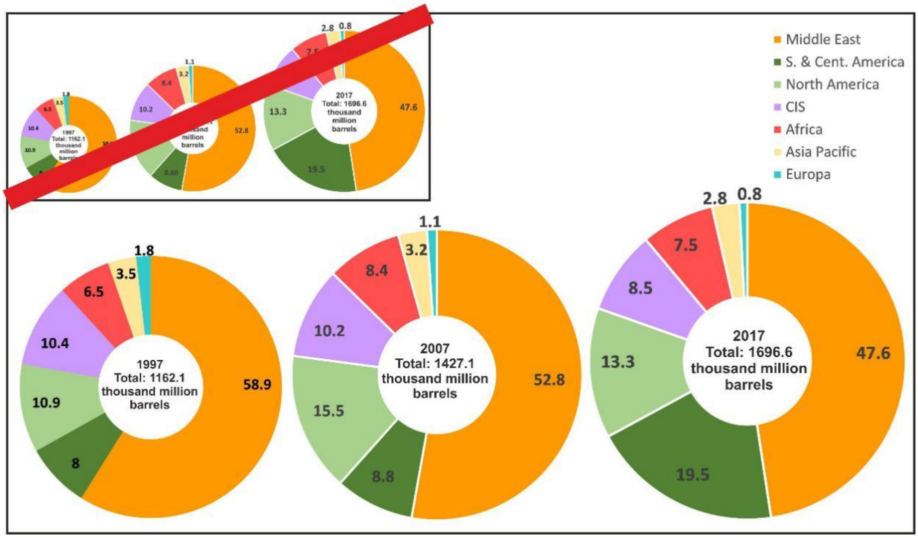

Fig. 9.7. Regional distribution of oil reserves in 1997, 2007 and 2017 (including the original BP 2017 figure and its re-edited version, where the area of the circles is proportional to the amount of real reserves)

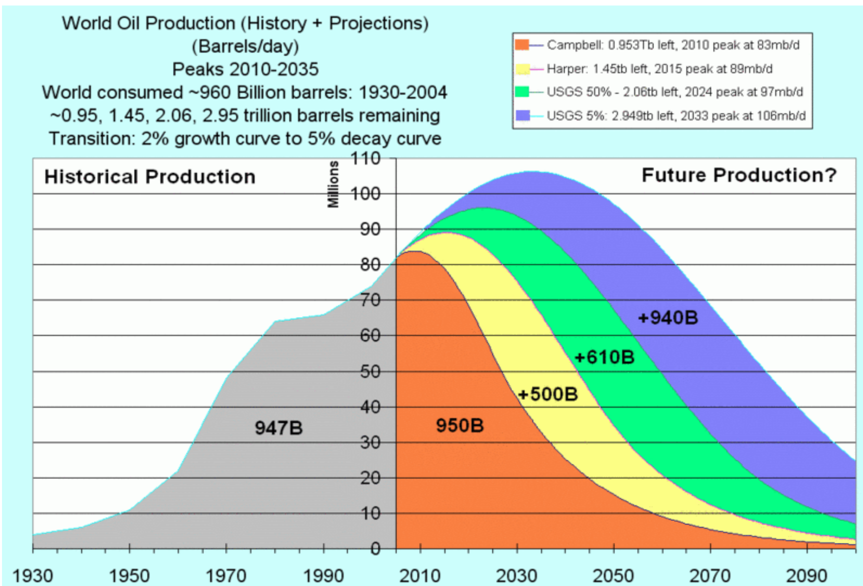

Fig. 9.8. Hubbert curves of oil production based on optimistic reserve scenarios (Source: Ruen 2005)

Discoveries and utilization are influenced by several factors. But assuming a 2-3 trillion-barrel increase in reserves, the modified Hubbert (Fig. 9.8) curve would indicate that oil will be available for up to four decades at today's level of consumption, but that the production peak may be experienced within two decades. The largest economic problems related to oil crises were experienced during the 1979–1980 crisis (the Iranian Revolution, then the Iraq–Iran War). At that time, oil prices jumped from $ 13 to $ 34 within a short time – while global production declined by only 4% because of the conflicts. Shortages are also due to the psychology of scarcity, hysterical purchasing, and hoarding. The severe global economic consequences of the price shocks were mitigated by an OPEC-coordinated production increase. We do not yet know what impact scarcity psychology will have when production can no longer be increased. If humanity is not prepared for this (no matter whether the peak comes next year or in twenty years' time) it may cause a serious world crisis.

9.2. Rare-earth metals (REM)

For a long time, people generally did not even know about the existence of rare earth metals[176] (and this statement is probably still true). The situation is interesting, because nowadays almost everybody uses equipment on a daily basis whose essential components are these elements. REMs are essential components of smartphones, some electrical equipment, LCD displays (TVs and monitors) and the hard disks of computers are made using the 15-17 chemical elements from the rare earth metal group.

These raw materials were at the core of attention when China announced in 2010 that it would reduce REE exports by 70% from the second half of the year and then cut them further from 2011. But why did this cause such a big problem throughout the world? In brief: because of the globalization of the economy. In order to understand the background, the introductory chapter of this book should be referred to, which describes the features of a globalizing world economy. An important feature of this process is that world market prices are crucial to the production of raw materials (or products). If a producer creates expensive products (e.g. because of geological conditions, expensive labour, or stricter environmental regulations) it will be displaced from the market if cheaper producers exist. This has also been the case with REE. Until the mid-1980s, the USA dominated the world market of around thirty thousand tonnes. China appeared on the market at that time, and has dominated it since the mid-1990s (due to cheap labour and less stringent environmental protection), while US production has almost ceased (Fig. 9.9) because the production that restarted in the early 2010s also ceased because of the bankruptcy of a mining company. Australia's production increased from 3200 tonnes to 20,000 tonnes between 2012 and 2017, but this is still less than a fifth of Chinese production (typically between 100 and 125 thousand tonnes), while the combined production of other countries did not reach 9,000 tonnes in 2017.

[176] These REMs did not even appear in the Meadows analyses as fossil raw materials.

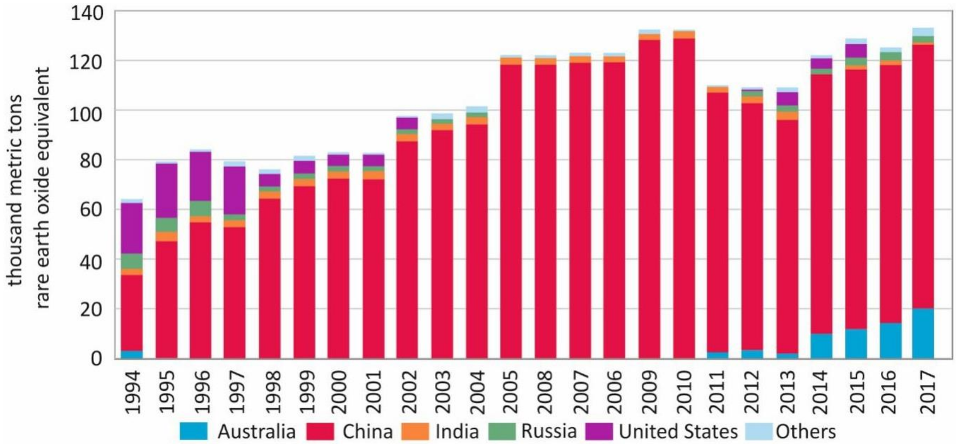

Fig. 9.9. Rare-earth metal production of the main producer countries between 1994 and 2017 (metric tons – rare earth oxide equivalent)
(Source: expanded from King 2017[177])

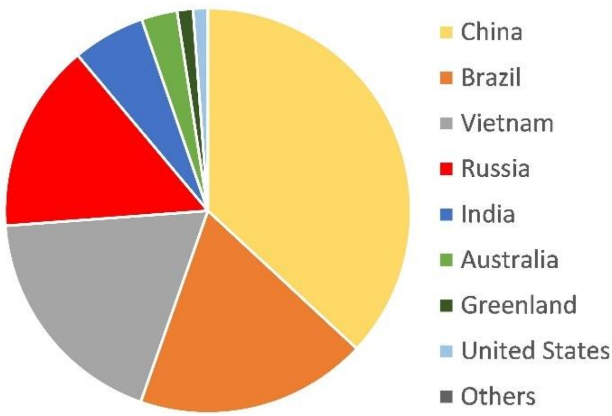

Fig. 9.10. Rare-earth metal distribution by country (2016)
(based on data from King 2017)

In terms of the world's stocks in 2016 (121 million tons), China is also first, but its dominance is not the same as with current levels of production. Brazil, Vietnam, Russia, India, Australia, and even the US have considerable reserves (Fig. 9.10). Knowing the data about stocks, it is somewhat surprising that Chinese companies are expanding abroad: in the rise in Australia's production, it was a significant factor that an Australian mining company acquired a Chinese company in 2009, but the Chinese have also expanded into Zambia.

[177] Available at: https://geology.com/articles/rare-earth-elements/, the data source for the year 2017: https://www.statista.com/statistics/268011/top-countries-in-rare-earth-mine-production/

The example of REEs for both producers and consumers conveys long-term lessons. Some say that China is using its monopoly position for economic advantage. It is seeking to incorporate the cost of very polluting mining and processing into prices, and also attempting to reduce illegal mining. But it can also be seen that China deploys its monopoly position as a political tool. In September 2010, a Chinese fishing vessel was stopped by the coastguard in Japanese waters (near a group of islands that both countries claim), China then stopped the export of rare-earth metals to Japan.[178] This shows the strategic role raw materials may play in the future. This response is also a serious warning to the US. The question is whether the world's largest economy will tolerate such vulnerability with a strategic raw material/product with regard to an economic/military rival. Whether this situation is acceptable totally depends on the world market, but in critical areas instead of profitability it may be thought necessary to attempt an autocratic approach, similarly as is done with military technology (for example, REEs are of high importance in many strategic sectors and also in the military).

9.3. Sand resources

When I saw the sandy coastal area of Singapore in 1996, I did not realize that I was looking at a raw material that would be included on the 'top materials list' in the first decades of the twenty-first century. However, over the last two decades sand has become one of the most in-demand raw materials, despite the fact that large areas of the Earth's surface are covered by deserts. But why has sand become so important that its international turnover has increased more than three times since 2000?

Aphorisms for futile activities are known around the world, such as 'carrying water to the sea,' and 'bringing sand to the beach.' But lo and behold, Dubai, built in the desert, and Saudi Arabia, with its more than two million km^2 of deserts, also import sand. This is because there is a huge difference between types of sand. Desert sand, with its small size and rounded particles, is not suitable for use in construction or industry.

The demand for sand has increased for several reasons, including the extensive urban construction and road construction going on in some regions of the Earth, while demand from industrial activities is also growing. According to some sources,[179] China used more sand in the last four years than the USA did

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[178] https://www.nytimes.com/2010/09/23/business/global/23rare.html
According to several data sources, the batteries in Toyota Prius hybrid cars require nearly 10,000 tons of rare earth material per year. In connection with this case, SONY has filed a complaint with the WTO.

[179] See: http://business.financialpost.com/commodities/alarm-bells-ringing-globally-as-world-begins-running-out-of-sand – 2017. September

in the twentieth century. More and more sand is needed for tourism development (creating sand beaches) and hydraulic fracturing technology, as well as for the creation of artificial islands and the expansion of coastal areas. Data about sand production and international commercial trade are very different[180]. This is because reported data are often not based on volume, but on the cost of transportation, and the illegal exploitation of sand resources is also very significant. According to a reliable source, the demand for sand of China and the United States are clearly dominant (Fig. 9.11). The figure shows that the demand for sand is expected to grow significantly in the near future, while production is causing increasing amounts of environmental damage.

According to a UNEP report from 2014, sand and gravel mining together account for 85% of all mining activities. One of the most greatest environmental consequences of sand production can be seen in Indonesia, where at least two dozen islands have disappeared since 2005, with the exploited sand resources ensuring the territorial expansion of Singapore (by 24%) over half a century.[181] A significant amount of sand has also been used by China to develop some previously insignificant reefs into islands with associated infrastructure in the South China Sea as part of its well-planned expansion.

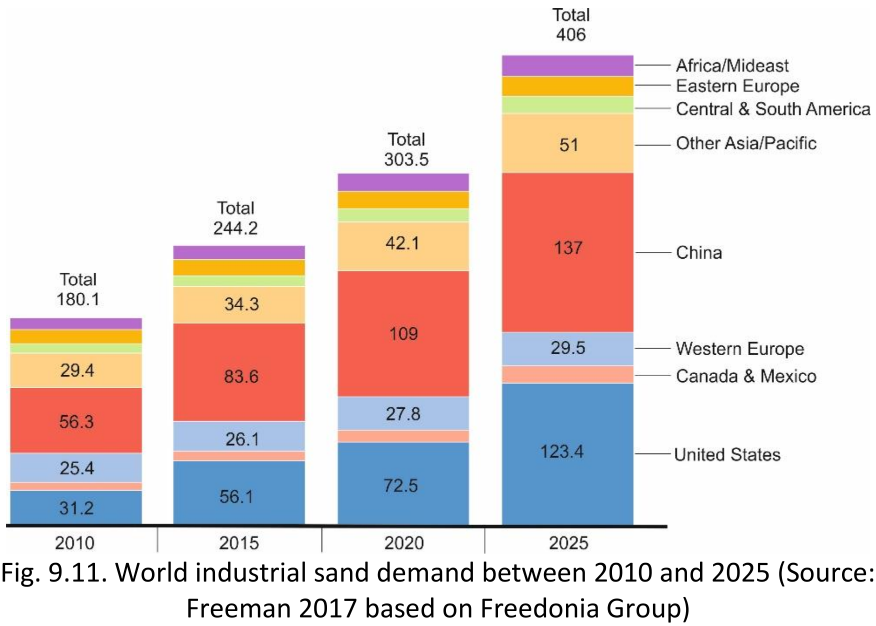

Fig. 9.11. World industrial sand demand between 2010 and 2025 (Source: Freeman 2017 based on Freedonia Group)

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[180] Cambodia's statistics can be a good examples of this. Cambodian statistics indicate 3 million tonnes of sand export between 2007 and 2015, while in the United Nations trading database, Singapore reported imports of 70 million tonnes from Cambodia for this period.
[181] Since the country became independent in 1965, its territory has increased from 581 km^2 to 721.5 km^2 (by 2018).

In agricultural areas in Southeastern Asia, illegal sand mining from river channels (e.g. from the Mekong River) causes serious problems. It probably enhances saltwater intrusion during the dry season, threatening local communities' water and food security. The rate of overexploitation is so high that the consequences can be observed on satellite images.[182]

Sand mining from rivers negatively affects rivers and coastal ecosystems (through habitat loss, and the spread of invasive species) and increases environmental hazards along the rivers due to the increase in erosion. Sand mining has serious social consequences as well. In India, organized crime groups are engaged in the illegal trading of soil and sand (e.g. along the Ganges River).

In Kenya, sand-bed rivers earlier provided water for normal living purposes even during dry periods, but the sand has now been depleted and the bedrock that remains in the channel beds has no water retention capacity, resulting in water shortages.

Although sand is continuously formed by the physical weathering of rocks, this process is slower by an order of magnitude than the rate of use, so there is a continuous decline in stocks.

9.4. How long will there be enough raw materials?

The raw materials described above have been discussed in detail because of their specific roles in global production. The material which will sell best over the next 1-2 decades is not yet known. Lithium and cobalt are good candidates for this list, but it is possible that a currently barely known material will turn out to be important.

Traditional materials that have been used for long time are not inexhaustible. The time they remain available, of course, depends on their future consumption, which is a recurring topic of analyses. One of the most common raw materials, coal, also seemed to be inexhaustible for a long time. For example, Meadows' analysis regarded it as one of the raw materials likely to be available the longest (111-150 years). However, the UK, the first industrial user of coal, had consumed 90% of its stocks by 1984. Based on a report from previous years,[183] the exhaustion of coal may occur globally around 2072, but production could peak at least two decades earlier based on Hubbert's curve.

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[182] The impact of sand production in the Yangtze River basin is clearly visible on NASA images by moving the boundaries of the images: https://www.smithsonianmag.com/science-nature/world-facing-global-sand-crisis-180964815/

[183] Moyer & Storrs 2010: How Much Is Left? The Limits of Earth's Resources. Scientific American.

We are running dangerously out of silver, which is now used not only in jewellery, but in combination with nanotechnology as an effective disinfectant. Stocks are sufficient for approx. twenty years at today's rate of use, thus recycling of silver needs to be pursued. At the current level of consumption, stocks of the less well known indium may also be depleted.

The production of currently common aluminium could peak in around 2035 and stocks may be depleted in around 2065. The solution may again be recycling, or the re-processing of by-products with better technology. Iron ore may follow aluminium with a delay of 10-20 years: recycling may also be the solution.

If these estimations are only roughly accurate, a significant part of the population that are alive today will face massive raw material shortages and the unavoidable need to recycle. Of course, in the case of several ores the 'non-conventional' exploitation of sea floor deposits may provide a solution. As a sign of this, Japanese researchers announced at the beginning of 2018 that rare earth metal stocks large enough to last hundreds of years have been found below the Pacific Ocean.

9.5. The environmental consequences of raw material production

When a plant or a person needs some raw material or a product, not much attention is paid to the environmental consequences. Unfortunately, associated damage to the environment is only partially incorporated into the price (as referred to in Chapter 17.2), which has serious consequences for humans today and also for the future. The consequences can be demonstrated in a few examples.

Mining can eradicate even mountains along with their entire ecosystem, destroy forests, or create landscape scars that are polluted beyond remediation. Such diverse environmental effects are demonstrated by Canadian oil sand exploitation. The volume of 'The Great Sulphur Pyramids of Alberta,' built from sulphur separated from petroleum and natural gas, exceeds the great Pyramid of Giza.[184]

The situation with German lignite mining demonstrates the different assessment of environmental problems from country to country. Germany decided to reduce nuclear power production and instead intensified surface lignite mining, which not only increases greenhouse gas emissions but causes notable landscape scars.[185] This causes serious environmental problems even if the rehabilitation of the landscape is done professionally. Mining and the related landscape damage is particularly extensive in economically disadvantaged countries where not much effort is paid to rehabilitation.

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[184] http://cosmobiologist.blogspot.com/2016/03/the-yellow-sulfur-pyramids-of-canada.html

[185] This can be confirmed by searching for 'Germany' and 'lignite mining' on the internet.

Underground mines often cause surface subsidence (even decades later). An illustrative example of this process is the enormous sinkhole that opened in the (abandoned) village of Solikamsk in Siberia,[186] or the sinkhole in Louisiana that formed as a result of salt mining and swallowed a forest.[187] Cement production also has a variety of environmental impacts, and not just due to quarrying, but also production and utilization, and is responsible for one-seventh of all the world's anthropogenic CO_2 emissions (see Fig. 5.23).

Offshore oil drilling can also cause major environmental damage. The 'Deepwater Horizon' catastrophe in 2010 (see Chapter 6.2.2.) is extraordinary, not just because of the damage it caused, but because of the more than $ 65 billion compensation paid by the oil company BP.

10. Utilization and consequences of nuclear energy

Fissionable materials for energy and military purposes are used by only a small number of countries on Earth, but the utilization of nuclear power causes global environmental problems. The consequences of a nuclear power plant accident or nuclear explosion affect regions far away from the location of power plant, thus such incidents cannot be considered the private problems of countries.

The use and application of nuclear power has gone through a specific path of development. It was introduced during World War II in the form of a new generation of deterrent weapons, and played an unbroken role until the end of the Cold War. The two superpowers of the post-World War II era manage enough nuclear arms to destroy the entire population of the Earth (and a large part of its wildlife). However, after more and more countries started placing restrictions on this powerful weapon, and the disintegration of the Soviet Union resulted in further uncertainties, the world's most powerful leaders are now making efforts to prevent the further propagation of nuclear arms.

10.1. Civil utilization of nuclear power

In terms of civil use, nuclear power was first regarded as a clean replacement of conventional non-renewable energy sources (although it was already known

[186] https://www.express.co.uk/news/weird/538775/Giant-Mystery-Sinkhole-Solikamsk-Siberia-Russia
[187] https://inhabitat.com/video-24-acre-louisiana-sinkhole-swallows-whole-trees-in-30-seconds/

that uranium is also a non-renewable raw material), while in recent years it has been considered a carbon-free energy source.

The first reactors started operating in the 1950s, and the 'career' of nuclear energy continued almost unbroken for nearly three decades (Fig. 10.1). On the surface, the Chernobyl disaster was considered to be the reason for the halt in the rapid growth of nuclear power. However, the truth is that there were several signs that nuclear energy was not the energy of the future – only these reasons received less publicity. Chernobyl made it clear to the public that even the peaceful utilization of nuclear energy involves great environmental and security risks (even without external interventions, such as terrorism). As such, this event undoubtedly caused a decline in further developments, but it did not mean the end of the utilization of nuclear power. However, the growth in the number of nuclear power plants over the last two decades was not enough to maintain the share of nuclear energy in total electricity production (it decreased from 17% in the 1990s to 11% at the beginning of 2018).

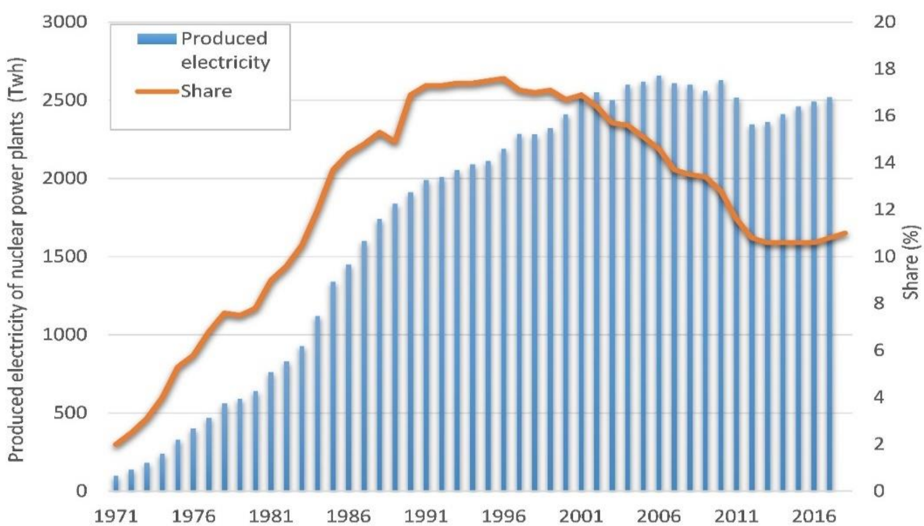

Fig. 10.1 Electricity produced by nuclear power plants and its share in electricity production globally (1971–2017) (Source: WNA)

In June 2018,[188] 450 nuclear power plants (the number of independent units) were operating in thirty-four countries around the world,[189] fifty-seven were under construction, and one hundred and fifty-four were at the planning stage (including four in countries which had previously not operated nuclear power

[188] Up-to-date data are available at: http://www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx

[189] At the given time, the number of countries was actually thirty because in four countries all of the power plant units were still under construction.

plants). Nuclear energy has become a leading source of electricity production in many countries. In 2017, the share of nuclear power exceeded 30% in twelve countries (Table 10.1). Eighty countries are responsible for 80% of global capacity; among them, the USA stands out with its 25%. The most significant developments in the next period is intended by China, Russia, India and the USA.

The utilization of nuclear energy has caused many environmental problems. Initial problems arose from a lack of knowledge about the properties of radioactive substances: without knowing the potential health impacts, nuclear power was used without care or responsibility. Anyone who is interested in the subject can see records about the first nuclear tests which were closely and personally watched or witnessed, and will learn that an American flotilla of obsolete warships from World War II were commanded (with all crew) to the Pacific Proving Grounds near to the nuclear test sites for the purpose of learning about the effects of atomic weapons on naval fleets. The uncertainty related to the effect of nuclear power is indicated by the fact that even in the early 1990s a stricter threshold dose of radiation had to be defined.

Table 10.1. Countries with Largest share of Nuclear Power Production (Source: WNA)

Capacity (MW) (April 2018)		*Share of electricity production* (%) 2017	
USA	99647	France	72
France	63130	Ukraine	55
Japan	39952	Slovakia	54
China	34647	Hungary	50
Russia	28961	Belgium	50
South-Korea	22505	Sweden	40
Canada	13553	Slovenia	39
Ukraine	13107	Bulgaria	34
Germany	9444	Switzerland	33
United Kingdom	8883	Finland	33
Sweden	8376	Czech Republic	33
Spain	7121	Armenia	33

The most challenging environmental problem related to nuclear energy is dealing with the safe disposal of the high-level radioactive waste of nuclear power plants and the further two hundred and fifty research reactors in fifty-five countries around the world. An average power plant reactor generates approx. 27-30 tons of high- and 200-350 m^3 of low-level and intermediate-level radioactive waste every year. Nuclear power plants also generated three hundred and seventy thousand tonnes of high-level radioactive waste by the beginning of 2018, of which one hundred and twenty thousand tonnes were reprocessed. The IAEA inventory estimates that the volume of currently solid, high-level radioactive waste (HLW) is approximately 22,000 m^3. Recently, it has become apparent that a totally safe method of disposal does not exist. In addition, little attention has been paid to the safe disposal of radioactive waste for a long time. The typical solution of the 1980s was simply to sink radioactive waste in various parts of the ocean. Even after international agreements, this 'sweep-it-under-the-carpet' practice only changed after protests by Greenpeace and the visual documentation of the activity. The best solution would be to dispose of radioactive waste in geological structures that are considered stable (i.e. are not affected by earthquakes or tectonic movements), and compact (i.e. impervious to water). This is easy to state, but it is very difficult to find a place suitable in all regards. The difficulty of defining suitable places is clearly proved by the fact that in the United States of America, the only place that could be found is Nevada's Yucca Mountains, but significant social resistance has been experienced. The burial of radioactive waste in geological formations is unquestionably a calculated risk (at a geological scale, even during shorter periods the occurrence of geological movements can hardly be excluded). In the case of the previously mentioned Yucca Mountains, it transpired that a nearby volcano was not 270,000 but less than 20,000 years old, for example. It is also very difficult to ensure that any underground disposal site will not come into contact with water.

The third major issue involves the safety of operations. Nuclear facilities are not an exception to Murphy's law: basically, anything that can go wrong will go wrong – especially if it is operated by humans.

10.2. Nuclear accidents

During the history of nuclear energy utilization, the 1986 Chernobyl disaster was a milestone and directed attention to many long-hidden accidents. Most of these accidents are not the focus of attention today, although the list is quite long.[190]

[190] Many nuclear accidents could be concealed before the start of satellite remote sensing because there was not enough evidence to identify them. In Sweden, even before the Chernobyl disaster, higher levels of radiation were measured coming from the direction of the Soviet Union, presumably due to accidents, but no information was provided about them.

In 1948, a radioactive cloud was released from the Hanford Site (USA, Washington State) containing 5500 curies of iodine-131. The public was not informed about this release because the danger of radioactive materials was not yet known. (Details about the event were only published thirty-eight years later, in 1986.)

In May 1952 and March 1953, a large amount of plutonium was released into the Irish Sea from the Windscale (UK) reprocessing facility, simply for the purpose of examining the effects. In 1957, a large amount of radioactive material was also released into the air during a multi-day fire.

In October 1958, at the Vinča Institute of Nuclear Science (Belgrade, Serbia), an accident took place with one of the research reactors. The research reactor became uncontrollable and significant neutron and gamma radiation was generated.

In September 1957, thirty villages were destroyed in the Urals, south of Sverdlovsk, by a major nuclear accident when a nuclear waste facility exploded. The explosion had a major effect on the environment, and several lakes lost their connection to the rivers that formerly flowed into them. One scientist who emigrated to the United States in the 1970s said that the explosion caused hundreds of deaths, while other sources reported the evacuation of eleven thousand people. This catastrophe is usually referred to as the 'Kyshtym disaster.'

In 1962, in Mexico City, a ten-year-old child found some radioactive material (cobalt-60 capsules) which had been extracted from an industrial X-ray machine and kept it in his pocket for a long time before taking it home. The boy died a month later, along with three of his family members in the coming months.

In the spring of 1966, there was a major explosion at the China Gobi-desert atomic weapon plant. More than twenty workers were transported to Beijing for medical treatment. Details about the event were only published in 1983. In January 1978, after a breakdown of the nuclear power plant in Tihange (Belgium), iodine-131 was released and about eighty people were contaminated with radiation. Also in 1978, due to the malfunction of the Platteville (USA, Colorado State) nuclear power plant's cooling system, radioactive gas affected the health of fifteen workers.

Prior to Chernobyl, the most significant nuclear power plant accident was the disaster at the Three Mile Island (Pennsylvania, Harrisburg) power plant in 1979. The partial meltdown of the reactor resulted in the release of radioactive gases and radioactive iodine into the environment. Two hundred thousand people had to be evacuated, and the increase in atmospheric radiation could be observed over a range of thirty-six km. However, the building was not damaged so seriously that that a significant amount of radioactive material was released.

The financial damage amounted to approx. $ 2 billion. The reactor resumed operations and was still working as of 2011.

In July 1983, there was a serious accident at the Volgodonsk (Soviet Union) reactor factory. In October 1985, a Welsh nuclear power plant (Tranwsfynydd) was shut down after a turbine caught fire at the station. In January 1986, in a uranium-processing plant in Oklahoma, a rupture in an overfilled uranium cylinder led to the death of a 26-year-old worker.

Eleven people died of radiation from an overdose and eleven were injured in 1990 in Zaragoza due to a failed attempt at medical treatment. A similar medical malpractice error occurred in 1996 in Costa Rica. Of the one hundred and fourteen affected patients, thirteen died.

This is how we arrive at the end of April 1986 in the Chernobyl disaster. The event occurred during a safety test and resulted in an explosion in Unit 3 of the power plant, and an associated fire. A wide range of radioactive substances were emitted from the heavily damaged building for ten days (of which iodine, strontium and caesium isotopes were the most dangerous) and transported in the atmosphere over large distances, significantly affecting distant landscapes across Europe. The amount of radioactive material emitted was seven tonnes, and the amount of radiation fifty million curies. The spatial propagation and deposition of the material was very diverse due to changes in wind conditions: differences of up to fifteen times could be observed within a 100 km range. The first reaction to the accident was to hide it from the world, and then to underestimate the actual problem. This fact is well characterized by the differences in published data: estimates at the time of the event specified thirty-one deaths, 130,000 evacuations, and $ 3 billion in damage. However, long-term estimates of deaths resulting from the accident have reached one hundred thousand. According to mid-ranging analyses conducted 15-20 years later, fifty deaths have been proven, while according to statistical analysis four thousand deaths and damage to the health of nearly one hundred and fifty thousand people are clearly linked to the accident. (Estimates of deaths over the long term are highly uncertain.) In addition to this, direct damage was estimated at $ 11 billion and indirect damage from $ 32 billion to $ 128 billion (based on different methods of calculation). Regarding long-term impacts (up to one hundred years' time) an area of 10500 km^2 can be considered polluted. In 2016, with EU support, a new sarcophagus was erected which should ensure safe conditions for the next one hundred years over the old and endangered concrete sarcophagus that had been built over the reactor unit that exploded.

In 2000, an accident occurred in a uranium reprocessing facility in Tokai-mura, Japan caused by bringing together too much uranium that had been enriched to a relatively high level, thereby causing the material to 'go critical', resulting in two deaths.

In 2001, in an Oncology Institute in Panama City, twenty-eight patients received multiple doses of radiation during medical treatment, resulting in seventeen deaths and other injuries.

The accident at the Fukusima nuclear power plant in March 2011 was rated seven on the seven-item International Nuclear Event Scale, similarly to the Chernobyl disaster. The accident was caused primarily by the 15-metre tsunami that followed a very powerful (9.1 magnitude) earthquake. The tsunami disabled emergency generators, thus three units lost the ability to properly cool their reactors and circulate water, leading to a nuclear meltdown. Subsequent studies found that the tsunami was much larger than originally estimated, reaching forty meters in some coastal areas. (This happened because, during the earthquake, a very large slip occurred in the shallowest part of the subduction megathrust.) Thus, although the accident was considered to be caused by human error – poor risk assessment –, without an unlucky series of natural processes the accident would not have occurred.

According to official sources, the radioactive contamination that was emitted due to the Fukushima accident was ca. 15% of the amount emitted by the Chernobyl disaster[191] (indirect signs, however, suggest that more radioactivity was emitted), while one serious environmental problem is that a significant amount of radiation entered the sea. The number of tsunami victims was nearly twenty thousand (15,700 deaths, 4,600 missing persons), although there were no direct deaths from the nuclear power plant accident. Subsequent analyses have shown, however, that the number of indirect deaths may even exceed one thousand.

The public still thinks that risk-averse attitudes to the future of nuclear energy started with the Chernobyl disaster but this is not true, as many important decisions concerning this energy source were made before this event. In the USA, in 1976, the state of California (and another seven states) initiated a moratorium on issuing permits for the building of new nuclear power plants while the problem of waste disposal remained unresolved. Austria decided in 1978 to stop commissioning its first reactor (Zwenterdorf) following a referendum, and after the Ukrainian disaster in 1986 the Austrian government decided to deconstruct it. In 1980, following a referendum in Sweden, the number of reactors in that country was restricted to a maximum of twelve, and a decision was made to stop using nuclear power by 2010.[192] In Denmark in 1985, a parliamentary decision was made to completely cease the use of nuclear energy. And, because of Chernobyl, the

[191] Based on reports from 2011, 770 PBq radioactive material was emitted, which amount was later decreased to 570.

[192] Although Sweden later modified its earlier concepts.

Philippine Government followed the example of Austria and did not construct a first reactor in 1986.[193]

The Chernobyl disaster primarily changed the ideas of those countries which did not yet have reactors about nuclear energy, thus the number of countries that use nuclear power plants has not increased substantially since then (the numerical growth of countries is mainly due to the disintegration of the Soviet Union into smaller states). The world's 'most nuclear' nations have responded differently. France, Japan and the Republic of Korea have made significant improvements to reactors, while the USA has developed considerably but more moderately compared to previous plans. Britain has also rationalized its plans, while countries with fewer reactors are mostly only maintaining their production levels. Sweden has reviewed its previous nuclear energy plans in several phases. Instead of the slow cessation of use of nuclear energy, the operating times of operating reactors were first extended in 1997 due to global environmental concerns and climate change, then several power plants were shut down in parallel with power plant upgrades. According to a decision made in 2015, another four power plants will be closed by 2020. Over the last two decades several strategic changes have been made in Germany about the future of nuclear power plants. In the 1990s, the building of several power plants was stopped and, after the 1998 elections, a plan was drawn up for their gradual shutdown. However, in 2009 the earlier withdrawal plans were abolished (partly because of major energy demand during a cold winter), while in 2011 eight reactors were permanently shut down following the Fukushima accident. According to current plans, several plants will be shut down by 2022 although they have certificates to operate until the 2030s. Because of this, the proportion of electricity now produced from coal is approx. 40% in Germany.

Italy is a different story: it started operating four nuclear power plants in the 1960s (1963–1978), but after the Chernobyl accident, based on a referendum in 1987, these were closed until 1990.[194] In 2008, the Italian government attempted to restart the use of nuclear energy, but in June 2011, following the Fukushima accident, Italians again voted against nuclear energy.

Moreover, the history of nuclear energy in Japan is also worth mentioning in a few sentences. After the nuclear trauma of World War II, the country's first nuclear power plant began operating in 1969, and since 1973, due to poverty of energy sources, nuclear energy has been a national strategic priority. Prior to the

[193] The Government of the Philippines paid the cost for the (never operated) power plant in 2007, but in the 2000s its commissioning was proposed several times. Most recently (in 2017) ROSATOM estimated the start-up cost of the plant at $ 3-4 billion. Not only is this level of cost alarming, but so were the strength of the Pinatubo volcanic eruptions in 1991.
[194] One power plant was even closed in 1982.

Fukushima accident, the share of nuclear energy from electricity production was above 30%. After the disaster, all power plants were shut down and subjected to technical review. After this, the majority of them were reactivated, but their share in energy production was only 4% in 2017, based on data from WNA.

Despite all the above-described environmental risks, the use of nuclear energy will take on new momentum in the near future. The forthcoming depletion of fossil fuel supplies puts the use of this risky form of energy into new light. Based on an estimation from the International Atomic Energy Agency (IAEA), the energy produced from nuclear power may double by 2030. It seems that in the future the world's most powerful leaders will reengage with this form of energy again, and panic about energy shortages will decrease the environmental awareness of societies. It is very clear that concern about nuclear power grows after a major nuclear power plant accident, but gradually declines with time. Interestingly, however, the effect of Fukushima on levels of fear concerning this energy source disappeared much faster than the effects of the Chernobyl accident.

In the future, more attention should be paid to the safety issues surrounding nuclear power plants. During the planning of many power plants, geological risks (for example, at Fukushima) were underestimated. There are power plants where these underrated risks represent a threat even now. Probably the most dangerous nuclear power station now operating is located in Armenia. This plant was designed to withstand a 7-magnitude earthquake and was shut down after an earthquake in 1988 (that caused at least twenty-five thousand deaths) but restarted after a six-year break in 1995 due to energy shortages. The planned closure in 2016 was postponed for ten years after the plant was renovated with the help of Russian experts. Several US power plants are also located in dangerous tectonic zones.

The hazards of using nuclear energy may also be compared with the hazards of using traditional energy sources. The number of deaths attributable to Chernobyl was approx. four thousand. Including the indirect victims of the Fukushima accident and the other 20-30 people who have died due to nuclear-related incidents in the last half a century, and the nearly one hundred people who have died due to inappropriate healthcare interventions across the world, the total number of victims is ca. 6000. This is less than the number of deaths in Chinese and Indian coal mines every year. Moreover, the harmful environmental impacts of greenhouse gases emitted from coal-based fuels must be mentioned. From this point of view, the question arises: is the use of nuclear energy really more dangerous to mankind? (Of course, the previously mentioned environmental impacts such as high-level radioactive waste must also be considered.)

10.3. Non-civilian use and its consequences

The military use of nuclear energy has been a top-secret subject for a long time, and even today only sporadic information can be obtained about the environmental impacts of military applications. The most widespread environmental impacts are connected to the atmospheric explosions of atomic bombs, because their effects have been detected across the globe due to global atmospheric circulation. During the Cold War, the radioactive content of the atmosphere increased (mainly strontium 90 and caesium 137 isotopes) until the Treaty on the Non-Proliferation of Nuclear Weapons in 1963. In the subsequent period, atmospheric testing was continued for years by China (in the Inner Asia region) and France (in the Pacific region) which countries were not signatories to the Treaty.

The production and processing of radioactive materials has caused environmental damage primarily in the producer countries, although it is quite sure that environmental protection was not a primary concern in terms of the military application of nuclear power. In the United States, the number of sites where serious environmental damage was caused by the nuclear arms race is estimated to be about one hundred. Only the sites near the Columbia River released about 379,000 cubic meters of liquid high-level radiation into the river, with an estimated radioactivity of 1.1 billion curies.

The other superpower, the Soviet Union, does not want for bad examples. The pollution emitted from the Chelyabinsk 40 nuclear production site into a nearby river was detected 1500 kilometres away in the Northern Arctic Sea. Lake Karachay has been described as the most polluted lake in the world after radioactive materials were released into it, thus even now a one-hour walk near the lake is enough to receive a deadly dose of radiation. In 1967, on a windy summer day, the wind carried radioactive dust away from the dried up lakebed over a distance of 75 km, irradiating 41,000 people. (The above-described accident in 1957 is also related to this plant.)

Environmental risks are not exclusively caused by manufacturing processes. About two hundred and twenty submarines and cruisers are currently operating using atomic power. At least six accidents related to atomic submarines are known of, of which the Russian Kursk is the only submarine which was returned to the surface. Very serious risks are associated with the used fuel cells of atomic submarines. In the Soviet Union, it was common practice to sink nuclear waste in the waters at Novaya Zemlya, while more are awaiting their fate on abandoned ships around Murmansk. According to a report from November 2002, Russian researchers have already identified two hundred and thirty-seven sunken radioactive containers (mainly submarine reactor sarcophaguses) in the Kara Sea. It is even more interesting that only airplanes belonging to the USA have lost at least ten nuclear bombs during their flights – most of them somewhere in the USA.[195]

Significant security risks are posed by the nuclear weapons that have been lost during the disintegration of the Soviet Union. Beyond providing inspiration for action movies, there are some revelations that should be considered. The creators of one educational film revealed during an investigation that at the time of the disintegration of the Soviet Union more than eighty one-megaton suitcase bombs had disappeared. The film suggests that Lieutenant General Lebed, who was once regarded as a successor to Yeltsin and who later died in an aviation accident, was disgraced because he wanted to investigate this issue.

The examples listed above are sporadic and probably only represent the tip of the iceberg. It is likely that similar events have occurred on the other side of the world, or in other countries where nuclear weapons were developed. And we have not even talked about the developments that followed Hiroshima. At the peak of the Cold War, the world had a combined total of over sixty thousand nuclear warheads. The reductions in the nuclear arsenal since then do not represent a significant change in the related environmental risk.[196] It is characteristic that the phenomenon of 'nuclear winter' which would be one global environmental consequence of a nuclear war was discussed in textbooks even during the 1980s. The occurrence of such a tragic event that would affect the whole of humanity would mean that there would be no sense in examining other environmental impacts. What is encouraging is that while the sense of responsibility of atomic powers seems to be growing, the importance of thinking about environmental issues is also increasing.

11. Soil: a conditionally renewable natural resource

How the opportunities offered by renewable natural resources are used will have an outstanding impact on future generations. Some of the former resources (fertile soils, freshwater) have been utilized for millennia without consideration to their renewal (or lack of it) due to inappropriate use. While

[195] See: http://mentalfloss.com/article/17483/8-nuclear-weapons-us-has-lost

[196] According to the latest estimates by the Stockholm International Peace Research Institute (SIPRI), at the beginning of 2018, 14,465 nuclear weapons still existed globally. While the total number of nuclear weapons has fallen slightly compared to the previous year, existing weapons have been modernized. The two superpowers (Russia and the USA) control 92% of all nuclear weapons (6850 and 6450 nuclear weapons, respectively).

such resources were available abundantly, little attention was paid to them. However, as a result of the fast-growing population and the environmental pollution that is a by-product of modern technology, associated problems have increased.

Fertile soils, generated over many centuries, are the most important criterion for food production and play a major role in meeting further anthropogenic demands (raw materials for light industry, biofuels, etc.). The associated problems can be characterized as three impacts: the limitation on the size of arable land, a decline in the area of production caused by environmental problems and urbanization, and the continuously decreasing amount of productive area per capita.

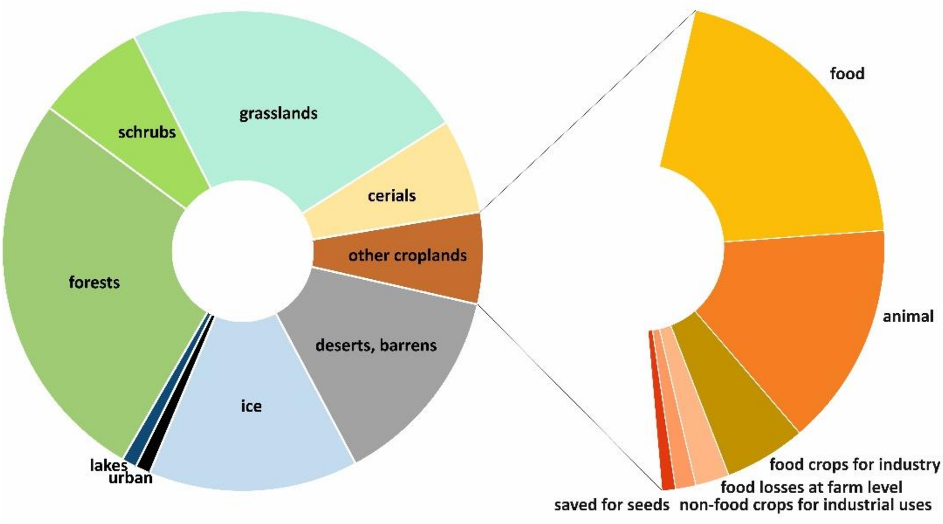

Fig. 11.1. Share of terrestrial areas according to type of use[197]

Due to natural physical-geographical limitations, almost one-third (35%) of Earth's terrestrial areas can be used directly for agricultural production (arable lands, meadows and pastures), while roughly 31% are not suitable for utilization (built-up areas, high mountain and ice-covered areas, deserts, etc.), and 27% are covered by forests[198] (Fig. 11.1). Thus, the area for

[197] Revised data about the expansion of the area of cultivated land from 2017 was taken into account when preparing the figure. Due to a lack of further information, it appears that this spatial expansion occurred at the expense of grassland and infertile areas (2:1 ratio).

[198] It is difficult to harmonize data from different sources even for such relatively simple issues. For example, the World Bank states that the extent of terrestrial areas is around 130 million km^2. In comparison, we have used the total extent following a geographical approach (149 million km^2).

production is limited and there is little opportunity for its extensive expansion. While humanity is attempting to expand its area for growing (for example, through deforestation, the cultivation of virgin lands, and irrigating desert areas), its activities mostly cause significant environmental damage and, as a result, cultivation is limited. The most serious environmental problems are soil erosion and the degradation of previously cultivated soils.

The global land area available for agriculture is nearly 50 million km^2, but a great proportion of this was not used by humanity for a long time. After the great geographical discoveries, its use accelerated: the area was only around nine million km^2 at the beginning of the seventeenth century but grew to 25, 38, and 44.5 million km^2 at the beginning of the twentieth century, and in the 1950s and 1960s, respectively. This growth continued until the 1990s when it approached the theoretical limit (Fig. 11.2). Only one-third of this area is suitable for growing crops. After the Second World War, in order to feed a dynamically growing population, total cropland increased dynamically to 14.4 million km^2 until the mid-1980s (this is about five times more than in the 1700s) and then began to decline slightly (2015: 14 million km^2). It has now reached a point associated with environmental and economic limits, thus the possibilities for an extensive increase in land use are now limited.

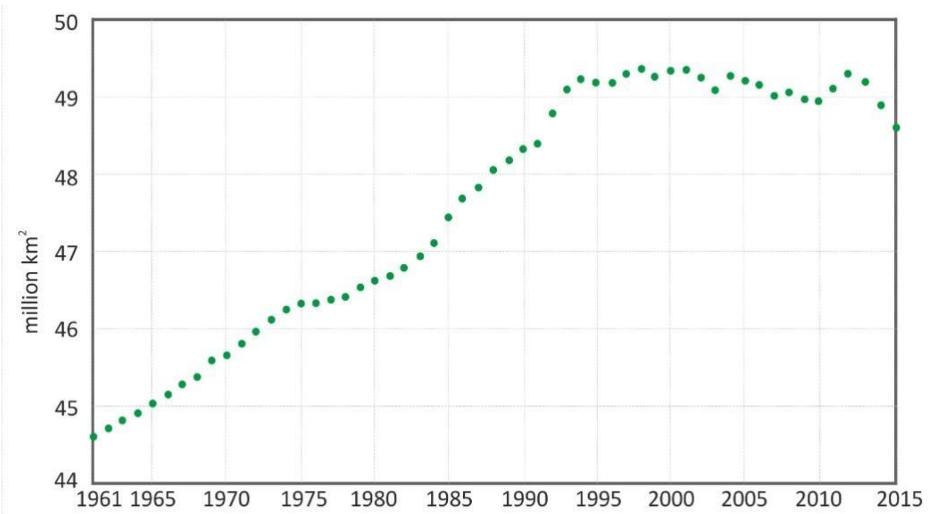

Fig. 11.2. Global Land Area used for Agriculture (1961–2015)
(Source: based on Fisher 2014, supplemented)

Along with the growth in cultivated areas, the expansion of grain production areas has increased spectacularly: from 5.9 million km^2 to 7.3 million km^2 between 1950 and 1981. Initially, the major reason for this was the cultivation of virgin Soviet land (mainly in the mid-1950s), while the increase in areas in the USA and Brazil became dominant in the 1970s (the area sowed with grain in the USA increased by about one-tenth between 1971 and 1975). However, a large proportion of arable land (more than 10%) was abandoned due to productivity issues in the Soviet Union and in China in the 1970s and 1980s. This meant that, after a peak in 1981, arable land area had decreased to 6.6 million km2 in 2002. The case of Kazakhstan is especially outstanding, where between 1980 and 1998 cultivation was abandoned over half the original area (!) of arable land, which areas were left to turn into grassland. Only in the last two decades has the size of cultivated area started to increase again. In the 2000s, the area dedicated to global grain production (2016: 7.2 million km2) started to increase slowly, in which irrigation farming in desert areas played a significant role, although this is a double-edged sword due to finite water resources. However, it has also been shown that cultivation and farming are possible on formerly infertile areas (Fig. 11.3).

Fig. 11.3. Irrigation farming in desert areas of Saudi Arabia using groundwater resources (Google Earth 2017 image)

A detailed assessment using satellite images published in 2017[199] reveals that the area of cropland is 15-20% larger compared to estimates using earlier published data, and the previously calculated 14 million km^2 should be modified[200] to 18.7 million km^2. Four countries share 35.6% of cultivated land: India (9.6%), the USA (8.9%), China (8.8%) and Russia (8.3%).

An improvement in the food supply of the growing population has been ensured by the increasingly intensive use of land in the past decades: total global grain production increased from 0.9 billion to 2.85 billion tons between 1965 and 2016. The improving production technology of China and India played a major role in these favourable changes. (Unfortunately, this data disguises the fact that the number of people suffering from hunger in the world has not decreased significantly.) Increasing yields are the result of the growing use of fertilizers, improvements in plant protection and, especially, irrigation, contributing to higher crop yields and food security. The size of irrigated areas reached a global extent of 1.2 million km^2 in 1955, and by 2018 had risen to 3.1 million km^2 , 71.7% of which areas are located in Asia. China, India, the USA and Pakistan have the largest area under irrigation (0.66, 0.63, 0.27 and 0.19 million km^2, respectively).

Intensive farming without sufficient environmental control has had serious consequences. Soil, generally considered a renewable resource, has suffered irreversible damage in many places. It was once thought that soil degradation was a problem for poorer countries, but the process has affected developed ones too. For example, in the USA – where the world's largest organization for soil conservation operates – soil erosion is significant, and it also causes annual losses of approx. $1 billion in Canada. In spite of such environmental problems, the US government has supported farmers to expand the area under production. However, such increasingly obvious soil degradation has also required action, and a law promoting soil conservation has existed since 1985. A world map of soil degradation (Fig. 11.4) reveals that, apart from the coherent forest areas of North America and Russia, there are hardly any larger regions where soil degradation is not causing problems. The rate of soil erosion was estimated at 0.3% per year by a FAO assessment in 2015, which corresponds to a decrease in area the size of a football field every five seconds.

Soil degradation has many causes and consequences. Causes include overgrazing (35%), deforestation (30%), improper agricultural practices (28%)

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[199]See: https://www.usgs.gov/news/new-map-worldwide-croplands-supports-food-and-water-security . A more detailed overview can be obtained by using the interactive maps available at:
https://www.croplands.org/app/map?lat=42.68244&lng=34.80468750000001&zoom=2

[200] Such a methodological change would result in difficulties in data series evaluation.

and overproduction (mainly due to biofuel production – 7%). A further cause is the withdrawal of land from agricultural use due to settlements, industrial facilities and transport infrastructure. Among the consequences, the most significant ones are erosion (responsible for about 56% of cessation of agricultural land use), deflation (28%), chemical degradation (unfavourable changes in the nutrient and carbon cycle, acidification, salinization, pollution – 12% in total), physical degradation (degradation of soil structure, unfavourable changes in the water cycle) and the decrease in biodiversity (soil life) associated with the above-mentioned factors.

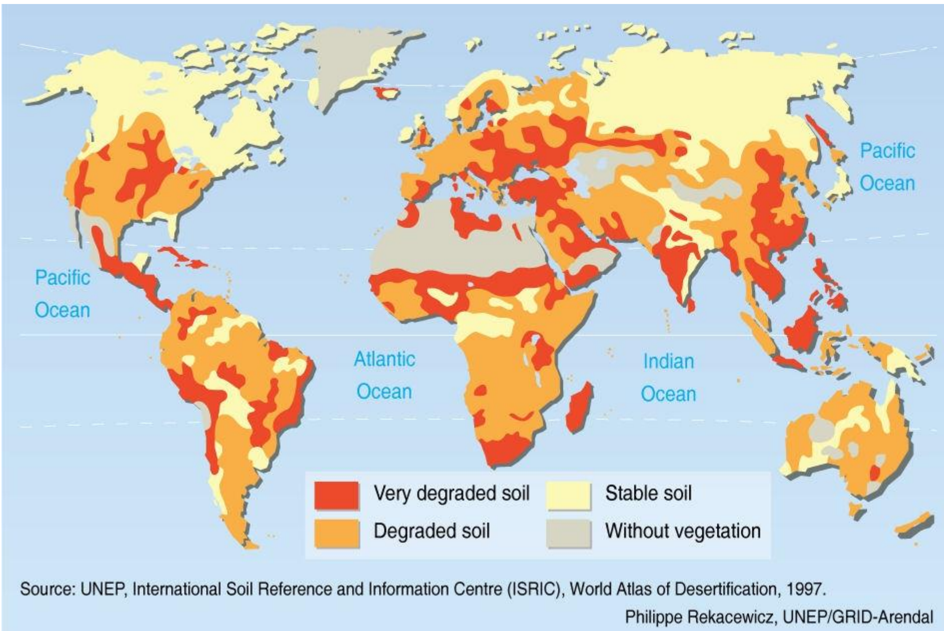

Fig. 11.4. Global soil degradation (Source: UNEP/GRID-Arendal)

Land degradation is a complex environmental problem. As a result of erosion, soil water retention capacity decreases, some nutrient content is lost, and soil thickness and fertility are reduced. Heavy rainfall rapidly erodes soils from open surfaces, but it is less known (only recently has pedological research highlighted the fact) that on such soils yields are much poorer because of the changed ionic composition due to soil loss. Another problem is that the eroded soil enters rivers and lakes, pollutes and fills up water bodies, and increases flood risk. In tropical areas, the well known environmental problem is deforestation. Such areas became infertile in less than a decade after trees are felled (land is generally suitable for cultivation for 3-5 years, and then grazing for 5-10 years). The result: abandoned areas unsuitable for forestry, with degraded vegetation. Experience of past decades has shown that the arable land obtained via deforestation only involves a temporary expansion in usable area. Due to deforestation, approx. 11-14 million hectares of forest per year are destroyed in the tropics (over thirty years' time, an area almost equivalent to the size of India). Sometimes forest soils are eroded to the bedrock level, thus, their use in agriculture becomes impossible (one good example of this is the Dinaric Alps in Europe).

The more intensive use of croplands also involves numerous hazards. Badly designed and implemented irrigation systems can result in swamping and secondary salinization. According to FAO estimates, around half of the world's irrigated areas are affected by these problems. For example, on an area of approx. 3-5 thousand km^2 per year cultivation is limited as a result of high soil salinity levels. Such a decline in production areas leads to the over-exploitation of existing areas, or attempts at territorial expansion that involve many contradictions. Since the Second World War, fertilizers and other chemicals have played an outstanding role in increasing crop yields, but their use has also bought challenges: fertilizers contribute to water pollution, and chemicals pose both a direct health hazard and an indirect one through their accumulation in the food chain (at the beginning of the 1980s, pesticides lead to an increase in deaths of approx. 10,000 per year in developing countries). The energy use required to create more productive agriculture is growing, but its effectiveness decreases after reaching a certain level, meaning that the productivity of agriculture can only be increased to a certain extent. Due to the limited possibility of expanding the area of croplands, the only solution can be improving productivity. However, crop yields in some countries are so high that they cannot, or only with difficulty, be increased, thus above-average growth should be pursued in areas with low yields – however, it is in these areas that the greatest economic and environmental problems are apparent.

More intensive agriculture requires more water (in the past half-century, water demand has grown 2-3 times). It is particularly risky when agricultural production occurs on water-scarce areas using non-renewable (so-called fossil) water resources. In these areas the groundwater level is significantly declining,[201] which will eventually lead to the termination of their use. It is also true that everything can be solved using money – at least for a while. After fossil water resources are used up, however, nature will not supply water, even for money.

[201] An animation illustrating the impact of irrigation on groundwater is available at: https://upload.wikimedia.org/wikipedia/commons/transcoded/0/02/Crop_Irrigation_Is_Closely_Tied_to_Groundwater_Depletion_Around_the_World.webm/Crop_Irrigation_Is_Closely_Tied_to_Groundwater_Depletion_Around_the_World.webm.360p.webm

Another problem is the continuous decline in productive areas as a result of the process of urbanization. The growth of settlements and agricultural land withdrawal related to infrastructural development (from road networks to golf courses) significantly reduces the area available for food production (not even mentioning other land-use related problems, such as the land used for tobacco or drug production). The impact of urbanization on production areas is closely related to economic development. The Santa Clara Valley in the USA was world famous for its apricot and other fruit production until World War II, while nowadays industrial and residential areas as well as transport networks determine its image – it is simply referred to as Silicon Valley. As a result of the sudden acceleration in economic growth, China lost 5% of its croplands between 1987 and 1992 due to urbanization. The importance of the problem is shown by the fact that the motorization strategies of the related countries has had to be reviewed over a short period of time. It was realized that the increasing number of vehicles required more roads and more garages, and their expansion – in already crowded built-up areas – could only be achieved at the expense of cropland. The build-up of croplands can be observed even in Egypt, which is dominated by desert areas. Although the agricultural production of the country is restricted to a few-kilometre strip along the Nile, urban land has started to expand over the cropland areas of Giza, which is famous for its pyramids (Fig. 11.5). Farmers can earn more from constructing houses than working in agriculture. The phenomenon is also common in other densely populated areas. I visited the island of Java in the mid-1990s and experienced that lines of settlements running for many tens of kilometers were typical along several important roads.

The problems described above, together with the population boom discussed earlier, have a cumulative effect: *production area per capita is constantly decreasing*. While the area available for global grain production per capita was almost one quarter of a hectare at the beginning of the 1950s, it is now no more than 0.1 hectares.

On the basis of the above-mentioned factors, the food supply of humanity (and ultimately, humanity's survival without conflict) depends on whether (and if so, for how long) increases in food production efficiency can keep up with the growth in the population. Over the past half-century perhaps the most important environmental problem facing humankind – the problem of food shortages – was solved, and this diverted attention from how the situation had been. However, it must be realized that the time for easy and extensive land acquisition had been completed by the early 1990s; the water resources of the Earth are under increasing pressure, and the use of soil, a 'renewable' natural resource is associated with many environmental problems. It is a major question how far the efficiency of agricultural production can be increased.

Fig. 11.5. Croplands turning into residential areas in Giza (November 2010 – April 2018) (Source: Google Earth)

12. Biodiversity

Life on Earth has changed continuously throughout history. For a long time, changes were controlled by natural conditions and the ability of life to adapt to varying circumstances. As mentioned earlier, the change in the composition of the atmosphere (e.g. ozone layer formation, in the conditions of which flora played a major role) allowed living beings to expand their habitat to terrestrial areas. Changes in environmental conditions caused major extinction periods that even happened almost instantly. The most well-known example of this was when a meteorite hit the Yucatan Peninsula 65.5 million years ago, which is linked to the extinction of the dinosaurs.[202] As far as is currently known, the most catastrophic extinction period was at the end of the Permian (about 252 million years ago), when up to 96% of marine organisms and around 70% of all the Earth's wildlife died.

After such a period, significant alterations in wildlife are characteristic and previously insignificant species can become dominant. During a slower change, a significant part of all wildlife can adapt to changes in circumstances and, for example, can find more suitable areas for living. Vegetation adapted to temperature changes between the glacial and inter-glacial periods by spatial shifts in vegetation zones. Similar effects due to global warming can also be experienced nowadays.[203]

Humanity has become a new factor in the alteration of the natural environment on Earth – numerous examples of this can be found in earlier chapters of this book. Its role in the changes is, of course, less dramatic than that of the meteorite mentioned above, but in terms of efficiency and speed – concerning wildlife – it is greater than that of glacial climate change.

12.1. Decreasing biodiversity

Humanity engages in several activities that impact living organisms.

a) *Direct loss of wildlife.* The related activity is quite variable: e.g. fishing, hunting, and deforestation. The purpose is food production (from simple foods to luxury ones, like shark fins, caviar or swallows' nests), obtaining raw materials, pursuing hobbies (hunting trophies, souvenirs) or for supposed physiological effects (e.g. the potency increasing impact of rhino horn).
b) *Habitat loss.* The biggest changes are due to changes in land cover: steppe or forest conversion to cropland, overgrazing of meadows, and built-up areas (settlements, roads).
c) *Habitat fragmentation.* As human infrastructure divides landscapes, the adaptation of wildlife to changing circumstances decreases, and the niche of some animal populations is reduced. Consequently, there is growing conflict between people and animals (e.g. the elephant in Africa and Asia, and the brown bear in Europe).

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[202] From time to time it is claimed that this extinction process started three hundred thousand years before this date.
[203] Research by the author of this volume discusses such changes. Available at: https://www.intechopen.com/books/climate-change-geophysical-foundations-and-ecological-effects/effects-and-consequences-of-global-climate-change-in-the-carpathian-basin

d) *Pollution.* The most spectacular examples of pollution involve the worldwide appearance of waste that causes many animal deaths, the effects of oil spills on marine life, or wildlife degradation resulting from polluted rivers. But animal poisoning (even unintended) or the degradation of vegetation or soil life is also frequent. The serious phenomenon of forest degradation due to the acidic deposition of air pollutants was mentioned earlier.

e) *Spread of invasive species* (often introduced by humans) that displace native species. Examples include the dingo in Australia, the cat in New Zealand, a snake species in Guam Island, rats in many places, and, among plants, the ragweed that causes allergies, etc.

f) *Climate change* as an indirect impact of anthropogenic activities. The high rate of coral reef die off due to temperature increases was described earlier, but the climatic zones in which numerous organisms live also change as a result of modifications in the climate.

The World Wildlife Fund (WWF), founded in 1961, has been monitoring the wildlife on Earth for a long time and publishing details about this in special volume (the *Living Planet Report*) every two years since 198204. The assessment is based on more than fourteen thousand monitored populations of 3,706 vertebrate species. The applied Living Planet Index uses current monitoring data to compare changes with the state in 1970. The combined impact is saddening: 58% of vertebrate populations declined between 1970 and 2012. The role of humanity in the changes is indisputable.

In the case of terrestrial species, the rate of decrease (based on a study that assessed 4658 populations of 1678 species) is 38%. The major cause of change is habitat degradation and overuse (Fig. 12.1a and Fig. 12.2a)[205].Freshwater habitats are in worst condition, since the rate of decline (881 species, 3324 populations) is 81%. The main reasons here are also similar, but water pollution is evaluated as responsible for 12% of this decline (Fig. 12.1b and Fig. 12.2b).

The degradation of marine habitats is similar to that of terrestrial ones (1353 species, 6170 populations); the rate of decline is 36%, but the trend in the changes is different. While there has been a persistent downward trend in other habitat types, here the decline (in line with sea fishing) was rapid until the early 1990s, and thereafter remained substantially at the same level. The main reasons for this are habitat degradation and overuse, but this form of habitat is also the most sensitive to the impacts of climate change (Fig. 12.1c and 12.2c). Coral destruction also affects the surrounding rich wildlife.

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[204] The reports are available at:
http://wwf.panda.org/knowledge_hub/all_publications/living_planet_report_timeline/

[205] For each habitat type, a more detailed evaluation is available in the report.

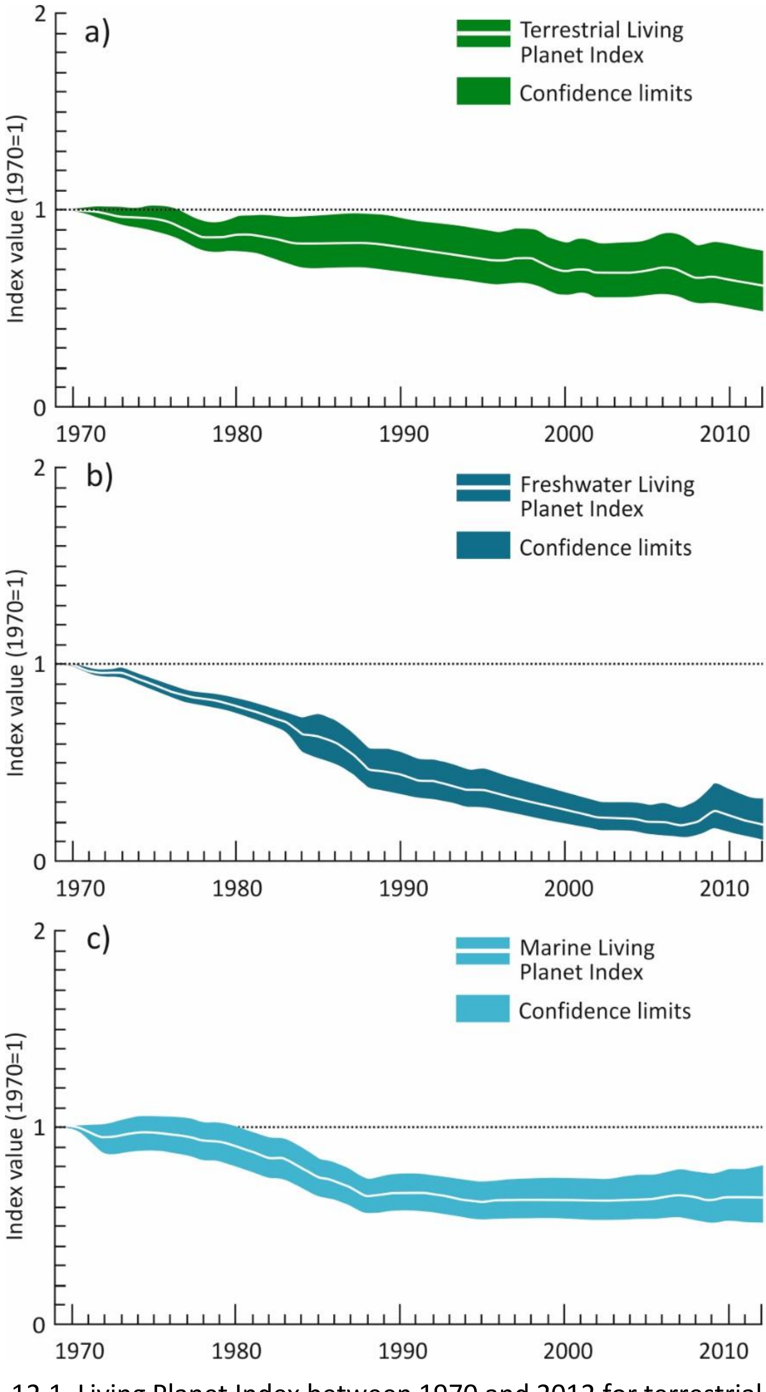

Fig. 12.1. Living Planet Index between 1970 and 2012 for terrestrial (a), freshwater (b) and marine (c) populations (Source: based on WWF 2016).

As far as the geographical distribution of the changes is concerned,[206] it can be concluded that the worst situation is experienced in the Indo-Pacific region (a 64% decrease) and the Neotropical region (50% decrease), including South America and its marine environment. The most favourable situation is in the Palearctic region (6% increase) including the northern parts of Europe, Asia and Africa, and furthermore in the Nearctic region (6% decrease) including North America. These big differences are due to two factors. One is the starting date of the assessment. In areas currently in a more favourable situation, intensive land-use changes occurred earlier (for example, if calculations were made using a period 300-400 years earlier, significant declines would also be obvious); furthermore, nature protection efforts started earlier and have been more effective. The other reason is that the most sensitive coral areas with their rich wildlife are found in the Indo-Pacific region, and the tropical forests with their rich wildlife in the South American region. Beside these areas, there is hardly any adequate habitat for natural wildlife in the densely populated areas of Asia, which is generally environmentally degraded.

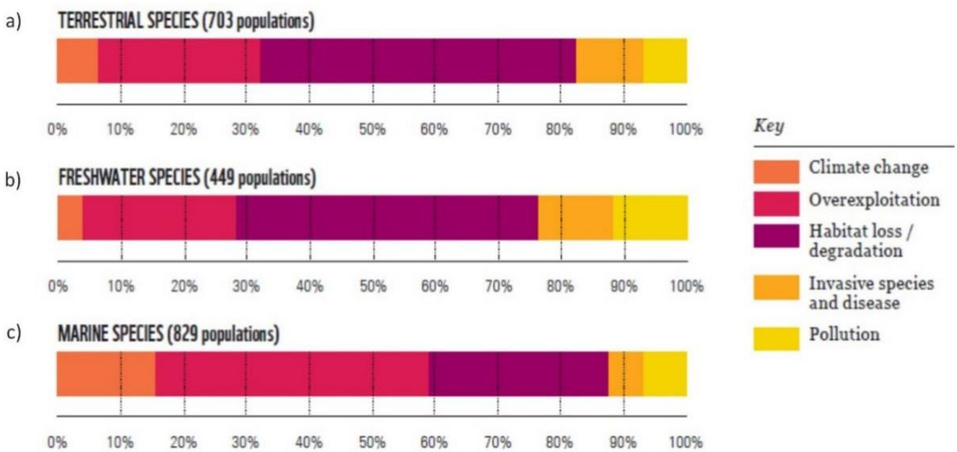

Fig. 12.2. Major reasons for changes in wildlife between 1970 and 2012 for terrestrial (a), freshwater (b) and marine (c) species (Source: based on WWF 2016).

12.2. The central role of humanity in biodiversity change

It might be assumed that humanity has realized its important role in preserving biodiversity for the sake of its own future. The increase in the number of national parks that were established following the last quarter of the nineteenth

[206] A figure illustrating this spatial distribution is available on Pages 34-35 of the 2012 Living Planet Report: http://d2ouvy59p0dg6k.cloudfront.net/downloads/lpr_living_planet_report_2012.pdf

century, the list of threatened species (the *Red List*), and the armed pushback against poachers may soothe some consciences. But extinctions are ongoing: elephants and rhinos are still killed for their tusks and horns (although this is forbidden and punishable) because of market demand. Whales are killed for 'scientific research' (often circumventing agreements and international conventions). Chemicals and plastics are released into waters in such large quantities that they endanger marine life. Moreover, areas with rich wildlife are popular recreational sites. I will never forget my trip to the Amazonian forests, or the howler 'concert' among the pyramids of Tical in Guatemala.

Maybe humanity does not even recognize the trouble it is in. The problem is not really perceptible when food is available on a daily basis (for ninety percent of humanity), mobile phone signals and internet are accessible, smartphones are in use all day, the number of cars is growing (along with traffic jams), and the Olympic Games and the Football World Cup can be watched in any part of the world. Humanity's significant dominance over biodiversity was highlighted in a book by Harari, published in 2015.[207]

Based on the previous chapter it can be concluded that we have exact knowledge about the number of wild vertebrates based on numerous pieces of research. This allows us to make a simple estimation: the mass of wild animals (larger than a few kilograms) is approximately one hundred million tons. The 7.6 billion people on Earth weigh approx. 300 million tons, and the weight of the livestock consumed in 2018 was 350 million tons, but not all of them are a part of our menu. The global cattle population is around one billion in 2018 (with an average weight of at least 300 kg), meaning an additional 300 million tons, of which 70 million tons are consumed. Thus, the total weight of livestock can be estimated at around 700 million tons. As a result, at present, the cumulative weight of human beings and their livestock is ten times greater than that of larger wild animals.

If we go back a half century, the weight of wild animals in 1960 was at least double the weight (minimum 200 million tons) than it is nowadays, and human consumption per person was also half that of present days (1960: 23 kg, 2018: 46 kg), thus, the three billion people on Earth at that time weighed one hundred and twenty million tons and meat consumption was approx. seventy million tons. However, the total weight of living livestock was hardly less than nowadays. For example, the number of cattle was only fifty million less compared to the nine hundred and fifty million nowadays, and there were more working stock. Thus, the weight of living livestock was also similar to nowadays (350 million tons). At that time, the cumulative weight of human beings and their livestock was only 2.7 times that of wild animals. If we go back five thousand years (BC 3000), the human

[207] Y. N. Hararai: Homo Deus: A Brief History of Tomorrow. 2015.

population can be estimated at forty-five million, and these individuals did not even have livestock, while the number of wild animals was several times higher (let us calculate using double the amount of the 1960s), while meat was mostly obtained from hunting. When considering the above-mentioned fact and the knowledge that the weight of livestock is probably overestimated as twice that of humanity, the weight of people and wild animals may be calculated as 5.5 million tons and four hundred million tons, respectively, suggesting that at least seventy times more wildlife existed than humans in terms of weight. Predictions suggest that in twenty years nine billion people will exist, the livestock of which will weigh 1.2 billion tons, while eighty million tons of wild animals will remain, equivalent to one-fifteenth the amount of livestock. These stark numbers clearly indicate how humanity is using wildlife and putting pressure on it. It is difficult to think about where this process will lead. It may seem pessimistic, but the process has similarities to the spread of cancer in the human body. I leave the Respected Reader to think over these facts further.

Humanity, however, not only has an impact on wildlife via its sheer mass, but uses the results of scientific research (biotechnology) to genetically modify it. Genetically modified organisms (GMO) may offer many advantages, but at the same time they can pose many risks. Through using GMO technology, for example, crop yields can be increased and medicine can be made more effective, but the longer-term health risks are not known. This uncertainty has led to several countries banning its use.

Another type of duality characterizes the role of humanity in terms of biodiversity: while, for example, monocultural farming in large areas reduces biodiversity, humanity is now operating gene banks to preserve the genetic diversity of wildlife.

13. The ecological footprint: an indicator of environmental responsibility

Decades after the perception of increasing environmental issues, assessments generally came to the conclusion that there were serious problems in several areas, as presented in the previous chapters, and that something should be done; furthermore, that richer countries are mostly likely to be responsible for such problems due to their over-consumption. Moreover, a novel environmental ideology, the concept of sustainable development, was born in the mid-1980s which was attractive to almost everyone and diverted attention from more problems.

In 1995, however, a book was published in Canada[208] that fundamentally changed the 'blurry' environmental ideology of sustainable development. The new concept that was introduced, the *ecological footprint*, provides an opportunity to define everyone's responsibility as regards the current state of the environment – including countries, continents, and even individuals. But what is this new concept? *The ecological footprint defines the area required to produce the goods necessary to support an individual's life without harmful consequences (i.e., in a sustainable manner!). It thus quantifies the impact of our lifestyle on the environment.* In the definition emphasis is paid to considerations of sustainability. Thus, the footprint does not simply refer to how much space is needed to support human lifestyles because that would also mean that, after the depletion, exploitation and contamination of an area (i.e. when resources are exhausted and an area becomes useless to us), we could move away. The method attempts to compare apples with oranges by converting human effects to territorial units using a specific logic. In the next step, it compares the land that is required with the resources that are available (firstly on a continent- or country basis).

According to the original definition, the ecological footprint of each individual is composed of six elements:

- the area required to grow the plants required for their food supply,
- the grazing land required to produce the meat they consume,
- the forest area sufficient to provide for their wood and paper consumption,
- the sea (more generally: water surface) necessary to support their consumption of fish,
- land required for housing,
- the area of forest required to sequestrate the amount of carbon dioxide that is proportional to the individual's energy consumption.

The calculation method was later extended with additional elements. The most important new element is that, in parallel with the ecological footprint, the water footprint has also been determined[209] – thereby recognizing the problem of fresh water shortage. (There have also been attempts to determine the nuclear footprint – using a highly debatable method –, but this was later rejected.)

The unit of measurement of the ecological footprint is a *global hectare*, which takes into account real natural conditions, thus is spatially differentiated. This means, for example, that in an area with unfavourable conditions for life (e.g. an arid area) more land is necessary to supply a person with grain than on

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[208] Wackernagel – Rees 1995: Our Ecological Footprint: Reducing Human Impact on the Earth. Its awareness-raising effect is shown by the fact that the method of measurement is now associated with a worldwide network.

[209] WWF: Living planet report 2008 – Available at: http://d2ouvy59p0dg6k.cloudfront.net/downloads/lpr_living_planet_report_2008.pdf

a Chernozem soil with high fertility. The calculation, therefore, evaluates not only the real consumption of individuals but also the natural background to this, or the biocapacity of the landscape.

One important element of the evaluation is how it takes into account not only what it is taken from the environment, but also what resources are available. If the whole world were incorporated into the assessment, the biocapacity indicator could give very unjust results as it would basically determine how successful (and maybe violent) descendants were in obtaining control over the territory of a country. Of course, there are some lucky turns here too: many of the big oil-producing countries are located in bare, desert areas that almost no one would have selected to live in one hundred years ago, while today many people are envious of them because of their riches.

In the Living Planet Reports,[210] detailed (even country-level) assessments about ecological footprint have been published since 2000. The following evaluation was made based on these. The time-series analysis shows that both biocapacity and the world's ecological footprint have increased globally over the past half century (Fig. 13.1). Concerning biocapacity, a more efficient agriculture (production and biotechnology) has had a much more favourable impact on changes than the negative impact of deforestation. The ecological footprint, however, grew much faster (about threefold) during the last half century as a result of significant population growth and a rise in individual-level consumption.

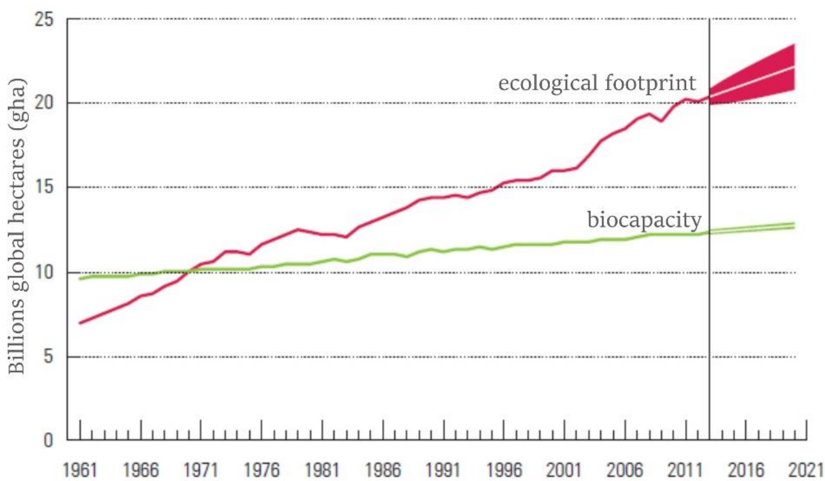

Fig. 13.1. World biocapacity and ecological footprint (1960–2012)
(Source: WWF 2016)

[210] As previously mentioned, they are available at:
http://wwf.panda.org/knowledge_hub/all_publications/living_planet_report_timeline
but information can be obtained directly from: https://www.footprintnetwork.org/

Before a more detailed assessment, it must be noted that, like all complex methods that try to compare apples with oranges, the ecological footprint may contain several measurement and evaluation errors. When calculating the ecological footprint, many important elements cannot be taken into account. Of these, for example, attempts have been made to integrate water use and nuclear energy, but they could not be properly integrated logically. But the lack of a waste indicator, or one for the consequences of environmental pollution, is also problematic. All these items could be taken into account in the calculation of biocapacity, and it would be reasonable to analyse their roles, but they do not fit the principles of the earlier calculations either. Furthermore, there is a lack of detailed enough data, which makes the accuracy of the determination of individual responsibility highly doubtful. As will be seen, however, the method is suitable for the temporal monitoring of environmental use and also for comparing the opportunities and use of resources in the related countries.

If changes per capita are assessed, a misleading picture may be obtained. The figures show that the global ecological footprint per person has not grown since the mid-1970s, but has even moderately declined. This is, however, not due to our increasing environmental awareness, but the fact that the footprints of the countries with a lower level of economic development are about a quarter of those for developed ones (Fig. 13.2), and – as was seen in Chapter 4.2 – it is in these countries that there is much greater population growth. Until the beginning of the 1960s, almost the same number of people lived in the developed and underdeveloped countries, but nowadays the population of the latter is at least three times that of the former. Therefore, over-consumption in developed countries is being compensated for by the higher population of underdeveloped ones. Absolute growth in impact is clearly shown in the previous Figure 13.1, which also indicates that half a century ago Earth's resources were enough to meet human needs, while nowadays at least one-and-a-half Earths are necessary. This means that resources generated over a long period of time are being consumed continuously.[211] It can be seen that, since the beginning of the 1970s, ecological footprint per person has been larger than available biocapacity (Fig. 13.3). Nowadays, biocapacity per person is 1.8 global hectares, while the ecological footprint is around 2.7-2.8 global hectares. As world biocapacity can only be increased at a slower rate, it will be possible to reduce our 'overuse' to a sustainable level even assuming immediate intervention only by the middle of the century. It is also obvious that overexploitation is in the range of 5-6 global hectares in developed countries. The overall picture is even more complicated if territorial data are taken into account.

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[211] In the calculations, biologically productive areas are estimated at 11.3 billion hectares.

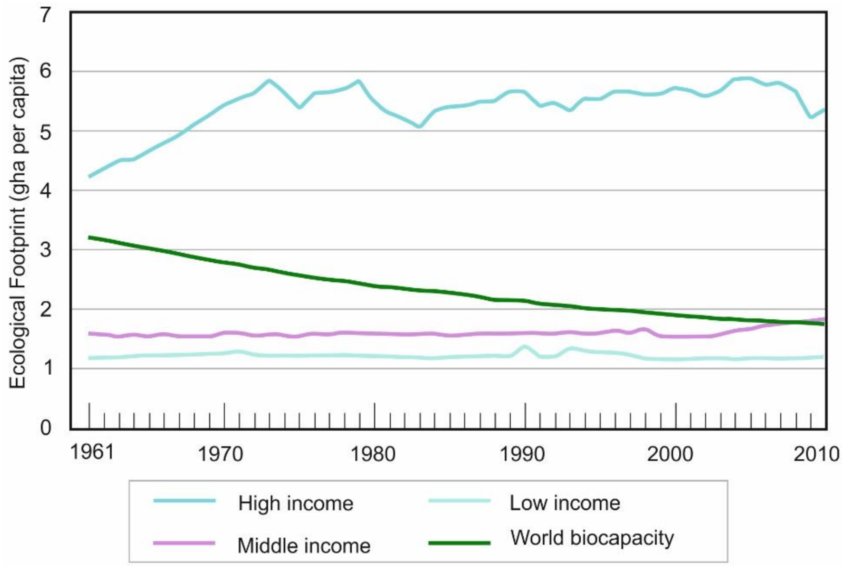

Fig. 13.2. Changes in ecological footprint according to the economic development of countries (1961–2010) (Source: WWF 2012)

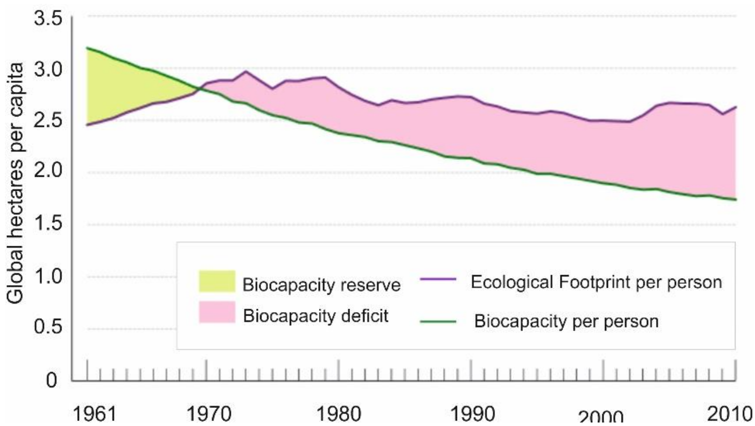

Fig. 13.3. Biocapacity per person and ecological footprint per person (1961–2010) (Source: WWF 2014)

If resources and environmental loads are assessed according to continents, huge differences can be observed (Fig. 13.4).[212] Only in Latin America is there less environmental load than biocapacity. Due to natural conditions, it is not

[212] In the figure, column width is proportional to population, while height is proportional to ecological footprint and biological capacity per person. Thus, the size of the rectangles shows the total biocapacity of the continents (dashed lines) and the total ecological footprint of the population.

necessary to have a great ecological footprint to overuse the environment, as the example of Asia shows. There are even more prominent differences at the country level. According to data from 2014, for example, the ecological footprints of India and Zimbabwe are 1.1 global hectares/per person, which is more than twice the available biocapacity (0.5 gh/person). In the detailed analysis it is a sad fact that the long-term changes in all countries are unfavourable: countries with high levels of biocapacity use their resources at a high rate, and the (often increasing) ecological footprints are higher in the majority of these countries (Fig. 13.5).

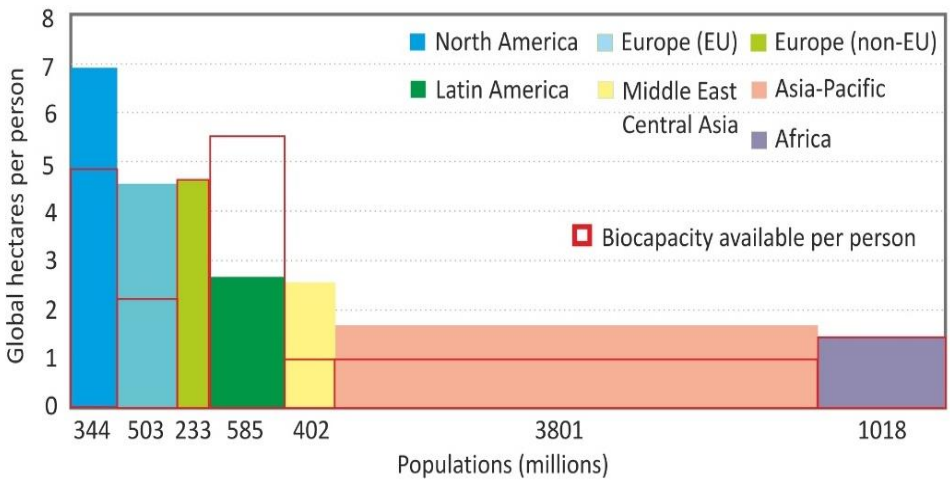

Fig. 13.4. Biocapacity and ecological footprint according to continents in 2010 (Source: EEA[213])

Assessment of the changes in the components of the ecological footprint shows that the carbon footprint is the most significant, and this has also changed most in past decades. This is clearly linked to the enormous use of fossil fuels. Due to humanity's food supply, the second most important element is cropland. Over half a century both components have multiplied in size (Fig. 13.6). It is clear from the figure that if humanity were able to reduce carbon emissions (or reduce their atmospheric concentrations), there would be a chance to harmonize biocapacity and ecological footprint. In this, developed countries could do most. In terms of the components of the ecological footprint according to economic development (Fig. 13.7), the carbon footprint is about two-thirds of the ecological footprint in developed countries, although it is also spectacularly increasing in the case of middle-income countries.

[213] https://www.eea.europa.eu/data-and-maps/indicators/ecological-footprint-of-european-countries/ecological-footprint-of-european-countries-2

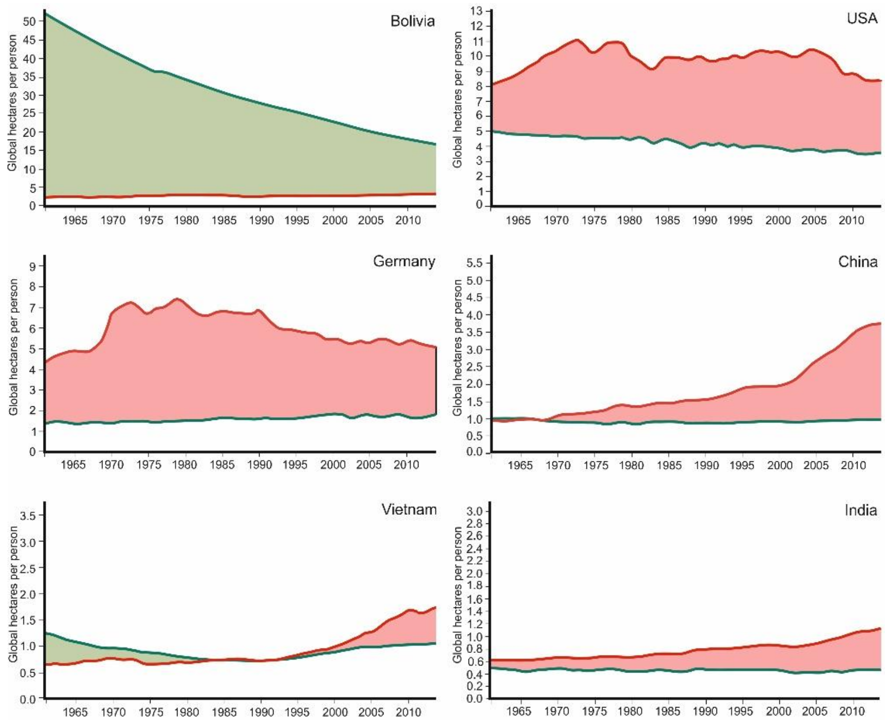

Fig. 13.5. Some patterns characteristic of the relationship between biocapacity and ecological footprint (1961–2014) (Source: Footprintnetwork[214])

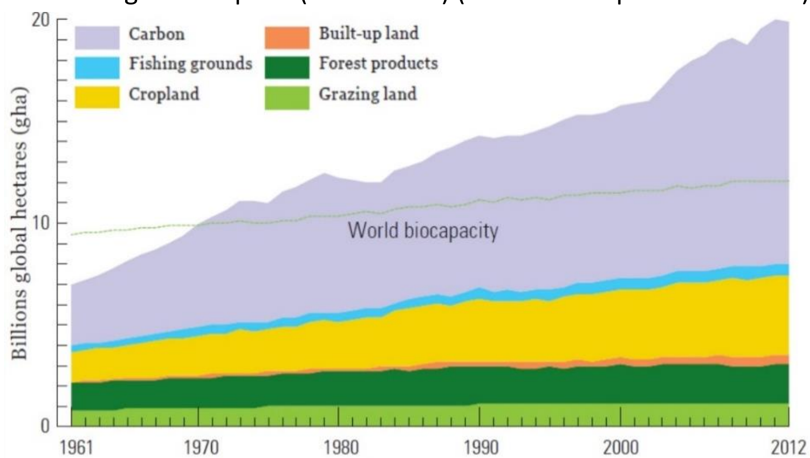

Fig. 13.6. Changes in the elements of the global ecological footprint (1961–2012) (Source: WWF 2016)

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[214] An interactive map showing detailed data about the world's countries is available at: http://data.footprintnetwork.org/#/

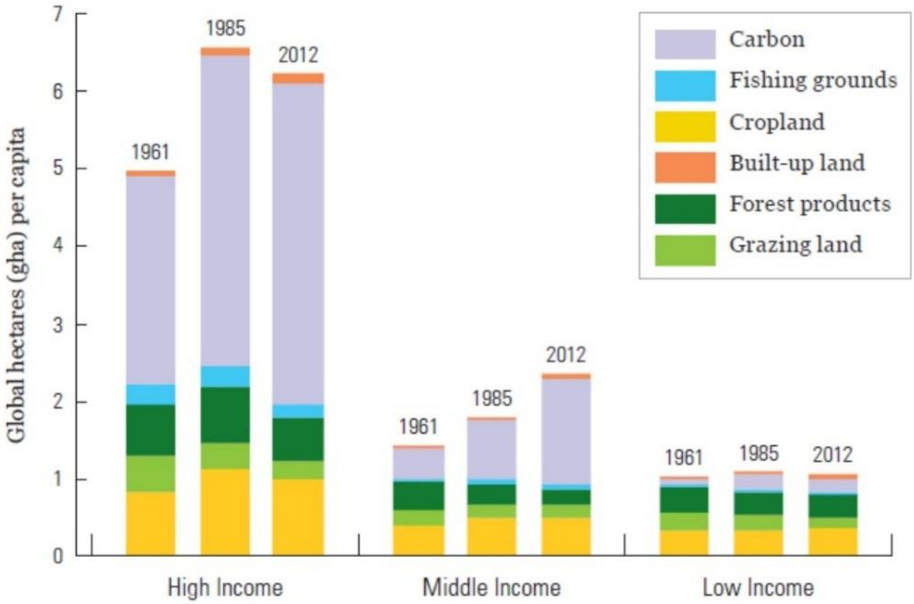

Fig. 13.7. Changes in the elements of the global ecological footprint according to the economic development of countries (1961–1985–2012)
(Source: WWF 2016)

As can be seen, the ecological footprint is a complex indicator that creates an opportunity based on environmental data to measure and compare the level of consumption of individuals[215] and countries, and also the resources available to them. The size of the footprint (i.e. consumption) in developed countries is considerably more than the resources that are available in these countries, or they have greater emissions. The fact that the footprint can be determined for individuals may also increase their sense of responsibility. The greatest significance of the indicator is that (despite its many inaccuracies) it confronts us with information about the limited resources on Earth and our ever-growing needs. The combined needs assessment integrated into this complex indicator reflects the fact that *sustainable development as a global environmental ideology is a realistic possibility neither at a global level nor at the level of most individual countries.* It also shows us that while humanity began to be familiar with the idea of sustainable development at the end of the 1980s, it has already exceeded the limit of sustainability because of rapid population growth (according to Wackernagel's calculations).

[215] You will find a calculator for individuals here, for example: http://footprint.wwf.org.uk/

The 'water footprint' created in 2002 had a much smaller effect. It is undoubtedly important to visualise the water supply of countries, but based on this their situation cannot be judged correctly. From the individual consumption point of view, it is important to know the economic importance of water. In terms of individual water consumption, the amount of water individuals consume per day is imagined (e.g., for drinking, bathing, toilet use, washing, etc.), but few people think about food. However, the production of 1 kg of chicken requires one quarter the water (3900 liters) as that of beef (15500 liters);[216] 1500 liters of water is required to produce 1 kg of cane sugar, and 2900 liters of water is used to produce enough cotton for a T-shirt. Just the water used for this T-shirt would be enough to supply a person with drinking water for 2-3 years. According to a cumulative index, supplying an average person with animal products requires 1150 liters of water a day.

Overall, the accuracy of the ecological footprint can be debated, but its basic idea is sound. Only facts can convince both decision-makers and individuals to act and live according to a different approach. In my opinion, it is less important if the ecological footprint of an individual is six or eight global hectares. However, if it can be shown that the footprint has increased, for example, by three times in twenty years using the same calculation method, the goal has been achieved. This means that it will be seen that a very bad situation is approaching, and the question is when it will be reached. A responsible decision-maker can not say in such a situation that I will survive but our children should live or die in poor conditions.

Based on the ecological footprint elements, another metric, *Earth Overshoot Day*, was introduced to demonstrate environmental responsibility. This shows in how many days annual biocapacity (renewable natural resources) on Earth is used up. According to the latest calculations,[217] this day is 1 August in 2018, which means symbolically that in the first seven months of the year the world's renewable resources for the year are depleted. If country-level data are compared this way (Fig. 13.8), it can be seen how quickly each country reduces its renewable resources. Thus, it shows the responsibility of countries whose

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[216] More information about the water footprint of foods is available at: http://www.fao.org/resources/infographics/infographics-details/en/c/218877/

[217] https://www.overshootday.org/newsroom/past-earth-overshoot-days/
Note that the yearly dates on the website have already been revised. Thus, anyone tracking the changes every year would experience significant modifications. For example, in the year of the economic crisis (2008), September 24 was originally defined as overshoot day, but the later-modified date was 15 August. (This is the reason for the differences between the findings of the internet search engine from 2008 and the present website.)

biocapacity is even greater than ecological footprint (e.g. Canada, Brazil, or Peru). In particular, the data of the former two countries are unfavourable: Canada and Brazil have renewable biocapacity of less than 2.5 and 6 months, respectively. Unfortunately, almost every country could be located on the overshoot figure (not only the nearly fifty that are illustrated), as the over-use of the environment is typical worldwide.

Fig. 13.8. Earth Overshoot Day in some countries of the world
(Source: Earth Overshoot Day 2018)

III. THE HUMAN RESPONSE TO ENVIRONMENTAL CHALLENGES

14. Environmental protection as a new factor

Some of the effects of environmental destruction have been recognized for hundreds of years (for example, the correlation between deforestation and soil erosion). Still, substantive measures were introduced only at the end of the nineteenth century when the focus was placed primarily on nature conservation. Yellowstone, the first national park, opened in the USA in 1872 with the aim of protecting items of natural beauty against the accelerating, large-scale exploitation of resources. In the nineteenth century, further national parks were established in Canada, Australia and New Zealand, and then in the early twentieth century in Sweden, Switzerland, and Congo. They were protected to such an extent that some of them refused to allow visitors to enter, or did not advertise themselves as tourist destinations. Not only have changes in landscape been striking, but also the diminution of fauna. In the early twentieth century, a number of national environmental protection associations and later international organizations came into existence, such as the International Council for Bird Preservation (or ICBP) in 1922, and the International Union for the Protection of Nature in 1948 (IUPN, and from 1956 known as the IUCN).[218]

Although the number of environmental challenges like air and river pollution have multiplied in the urban environment, business activity almost entirely lacked environmental awareness. If society needed something, it got it as simply as possible (Fig. 14). For instance, if there was a need for energy, a coal mine was opened, which may have had the appropriate technological background but cared minimally for its effects on the environment. When agriculture encountered a large number of pests, chemicals were used to get rid of them without preliminary testing for wider impacts.

After World War II, greater demand and increases in production triggered a series of harmful effects in the form of environmental disasters of different proportions. In the infamous Great Smog of London in 1952 the number of fatalities topped four thousand. Rachel Carson's famous book drew attention to the irresponsibility of using chemicals,[219] and there were numerous industrial catastrophes as well. These all played a major role in the fact that since the 1960s several new factors and a new viewpoint, namely, environmental protection, have emerged to fill the gap between demand and its realization (Fig. 14.1b). The new

[218] International Union for Conservation of Nature and Natural Resources
[219] Silent Spring, 1962

multidisciplinary environmental science introduced a novel focus on social action. Science is striving to create environmentally friendly technologies, while engineering aims at improving safety. The new approach is enforced by various means: for politics it means creating an institutional system and legislation, for civil society it refers to social pressure, and for education and the media it involves raising awareness. The spread of this environmental approach is a major step forward. However, even today this is an isolated movement and its effectiveness is significantly dependent on economic development. Today, when developed countries define their social requirements, environmental awareness claims its place. For instance, in order to protect the environment more and more people are purchasing electric cars. We push production to become more environment friendly, and environmental policy to take efficient action against environmentally harmful activities, if necessary. However, environmental awareness is uniformly effective neither at the economic nor at the social level, not even in a single country. Instead of preventing the development of health issues caused by environmental problems, we try to cure them. At an overall social level, prevention would be much cheaper, although the costs would be incurred earlier, and in the profit-oriented sector. Of course, we admit that the widespread promotion of environmental awareness is time-consuming, but there are some promising examples.

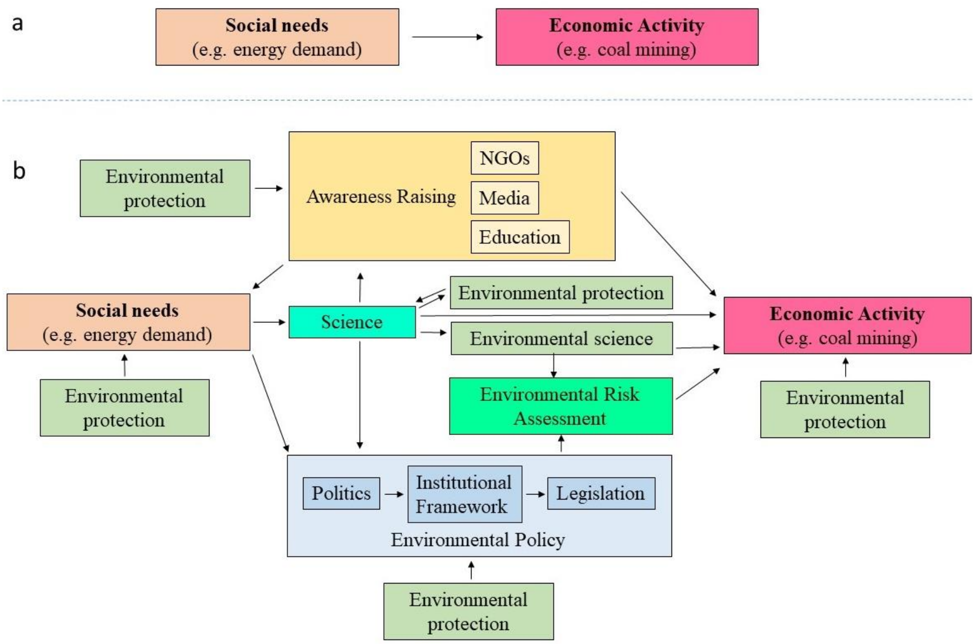

Fig. 14.1. The process of meeting social requirements without environmental protection (a) and when taking environmental protection aspects into account (b)

The world models described in Chapter 3 considered environmental protection a process of major importance. The Leontief model, for example, takes the status of economic development into account when calculating environmental costs.

In opposition to its name, environmental protection is not a passive activity. It includes recognizing problems, preventing harmful effects, eliminating damages that have been caused and developing the environment. Modern environmental protection 'thinks' globally and considers the territorial coverage of many problems.

Without detailing the accomplishments of environmental protection, we can state that it has successfully dealt with several serious problems when resources and political will existed. But the previous chapters also prove that more important problems remain that have not been resolved. Moreover, the success stories have mostly happened only in the richest regions of the planet. The formerly air-polluted London and other western metropolises have become clean; rivers which used to resemble sewers now provide a living; a growing number of electric cars are being used in transportation; waste from selective rubbish collection can be used as raw materials; and the role of renewable energy is increasing, etc.

An important feature of environmental protection is that it is human-centered; that is, it is rather selfish. Environmental limits are determined to conform to human capacities. Moreover, environmental protection increases the disparities between countries and regions at different levels of economic development. Living conditions improve in regions where financial resources allow measures to be taken. Where such resources are lacking, not only are living conditions worse, but life expectancy is also lower. Development of environmental protection and environmentalism is not necessarily a constant expansion. These issues can sometimes drop out of the political interest or their tools can be weakened even in the developed countries. A characteristic example is the climate policy of the USA after 2016, but even in the case of the EU with its environmentally strongly integrated policies a certain setback could be detected in the 2000s concerning the considerations on sustainability and environment in its overall development goals.

However, environmental protection allows great scope for civil initiatives. Communities may improve their situation by adopting an active role, such as promoting waste disposal, the development of green areas, etc. As united groups, or by raising public awareness about international problems they are able to stimulate state action, like improving water quality or legal regulations. Following this path, Greenpeace, perhaps the most well-known international environmental organization, played a prominent role in eliminating the disposal of nuclear waste in the oceans and reducing whaling.

15. What can science do?

In past centuries, based on the findings of science, technological, economic and medical development reached an extremely high level. However, the environment has paid a very high price for this. It is the unwisely or carelessly used results of science that can be held responsible for our environmental issues. For example, the miraculous pesticide DDT was quickly discovered to be poisonous. CFCs and similar substances which have a neutral effect in the lower atmosphere play a major role in ozone depletion in the stratosphere. Mechanization and the energy industry use a tremendous quantity of hydrocarbons, while the large amounts of CO_2 along with other anthropogenic pollution emitted into the atmosphere contribute significantly not only to global warming but also to other unfavourable changes such as the acidification of the oceans. The discovery of plastic has made our life easier and more comfortable in many areas. It is a cheap substitute for a number of materials. On the other hand, it has become the most notable and perhaps most dangerous element of waste material both on land and in the sea. These are only a few examples, while we should also add that in the case of some scientific developments, such as the invention of the atomic bomb, it was clear from the beginning that the purpose was anything but humanitarian.

However, the causes of environmental problems are said to be based on three pillars. Apart from science, people, and the growing demand of mankind may be held to blame.

Funnily enough, it is the findings of science that have the greatest promise for solving global challenges as they have already helped deal with numerous problems. One achievement of science is that we now know about major environmental challenges. It is a fact that in certain areas of the world environmental conditions are improving. Still, with a wide range of methods of measurement, many environmental emergencies have been revealed (ozone-related issues, acid rain, some chemicals, etc.) that required social intervention and forced politicians to take action. Undoubtedly, science has played a major role in reducing hunger, fighting against epidemics and diseases, utilizing energy more efficiently, developing alternative energy sources, and discovering and mining new raw materials.

The Meadows models were justly accused of underestimating the importance of science. When the first artificial satellite, Sputnik, was launched into Earth’s orbit, visiting the moon seemed a very distant goal. But amazingly, this actually happened less than fifteen years later. In the past decades we have become accustomed to the fact that science and technological development can make our ideas a reality – it is only a question of time and money. Many environmental challenges have already been dealt with. In the 1990s the main problems related to land-filling were vehicle tires and the large amount of plastic bottles which were said to take hundreds of years to degrade. Twenty years went by, and now we use them as recyclable raw materials.

Although science has managed to tackle numerous problems, it is not omnipotent. At the moment eternal life exists only in fairy tales. There are many ideas about how to solve our global problems. For example, there are various proposals for collecting and utilizing marine waste (they only need financing), but we have no chance of getting rid of the micro-plastics that pollute our waters. We know about plenty of water purification technologies, but we should know what to purify our waters from in order to be able to apply them. It is possible to analyse individual samples, but carrying out such tests on an industrial scale is unaffordable, at least in the foreseeable future. There are success stories, but they don't work everywhere. Hydraulic fracturing, which was successfully used in the USA for ramping up petroleum production, did not deliver results in Hungary due to the different geological conditions. Moreover, in many cases a seemingly successful solution exacerbates another problem. Typical examples are agricultural mass production based on non-renewable fossil waters in desert areas, and the environmental effects of oil sand extraction in Canada. In many cases, the global dissemination of effective solutions is hindered by the enormous cost that is involved, or the limits of raw materials.

Thus, science may be efficient at dealing with a large number of environmental challenges, but it is not able to create a new, or a threefold bigger planet.

16. The undertakings of politics

Many criteria must be met before we can efficiently handle global environmental problems. First, we must engage in global thinking, even if countries are affected to different extents. Second, we need reliable methods of evaluating variables which enable us to make decisions and take action. This is the starting point of the responsibility of environmental policy.

A typical way to handle problems is to underestimate them, thus postponing substantive decisions. If we want to find the underlying reasons for such attitudes, we should know that the challenges described in the previous chapters require conscious environmental policy, a lot of money, the reconciliation of different interests, and the cooperation of many opposing parties. We should be aware that, depending on their short- and long-term interests, actors from different countries and economies and societal representatives at different levels are very much divided, and are usually not interested in solving global problems in the short term as this would entail some kind of restrictions. Consequently, even if problems are commonly recognized, effective measures are implemented very slowly, data are evaluated according to individual interests, and scientific results are easily brushed under the carpet owing to their possible uncertainties. As a result, adequate international agreements are based only on common interests, and are realized at a later point with associated limit values and restrictions. Only grave situations result in quick, specific decisions. In connection with this, we may recall a disaster movie in which a giant meteorite is threatening to crash into the Earth, but the militarily opposing superpowers are willing to join forces only when they realize that on their own they are destined to fail. As we saw earlier, our planet's future is threatened by several environmental meteorites, so joint action is inevitable in many fields. The first 'meteorite' of this kind had an impact on environmental policy following the discovery of the ozone hole in 1985 – see Chapter 16.2).

A global approach to problem solving was initiated by the world models in 1970. Based on the knowledge and the challenges of the age, the problems which were deemed critical were population growth, food supply (the two are closely linked), the scarcity of non-renewable resources, and environmental pollution. Usually, they were politically addressed at the country level, and according to the extent of countries' involvement. Therefore, in developed countries, mainly in Europe and in the USA, closer attention was paid to environmental protection, while in the rapidly growing Asian countries the focus was placed on the green revolution and state-influenced population control (principally in China and India).

The first step in the comprehensive realization of regional-scale environmental policy was the environmental protection action programme of the European Economic Community. The first programme was accepted in 1973 and determined the most important environmental policy principles and areas for intervention. Through organizing comprehensive conferences about the environment, the UN undertook a coordinating role at a global level.

16.1. Earth summits

16.1.1. Stockholm 1972 (the UN Conference on the Human Environment)

Global environmental thinking was set in motion by the concern of the secretary-general of the UN (see Chapter 3) and, more importantly, by the facts that inspired the creators of the various world models. Showing the globalization of environmental policy, the first global environmental summit, at which one hundred and thirteen countries were represented, was held in

Stockholm in 1972. The four major documents accepted at the event were the following: Declaration on the Human Environment; Declaration on Principles; Action Programme Proposals; and, Organizational Measures. With environmental awareness gaining momentum (through the 'We have only one Earth' concept), the spirit of the conference reached every corner of the world within a short time.

There were many parties who harbored suspicion about the conference. Developing countries regarded environmental issues as problems of developed states, whereas the majority of socialist countries made political excuses to avoid attending.[220] However, these conferences made many realize that environmental emergencies can arise in peaceful circumstances as well. Conference-related evaluations presented a wide range of environmental disorders. However, they did not perceive the severity of a large number of problems correctly. Assessments about the future of nuclear energy and the potential risk of the greenhouse effect and the factors which influence it were highly controversial.

Nonetheless, the conference produced several results. Owing to a proposal, the United Nations Environmental Programme (UNEP) was established with its global base in Nairobi, and the UN declared the 5th June to be World Environment Day.

Four-and-a-half decades later it may come as a surprise to us that such a large number of problems had been identified at the time of the birth of environmental thinking, although our knowledge about real challenges was still rather limited.

16.1.2. Rio de Janeiro, 1992 (UN Conference on Environment and Development)

In the 1980s more and more environmental problems which required real global solutions were identified, such as acid rain, the ozone layer issue, global warming and deforestation. The resulting environmental world conferences and the action of environmental organizations proved that people and governments were indeed recognizing that economic development and environmental issues were inseparable. We discovered new facts, like the

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[220] According to one feeble excuse, the German Democratic Republic (GDR), not being a UN member, was not invited. The truth is that socialist countries in this era were reluctant to speak about environmental problems, as the latter did not fit with the image of a planned economy. At the same time, the problems were already at the stage of research. In 1974 the Executive Committee of the CMEA determined twelve independent research areas in the field of nature and environmental protection and management. The author of this book took part in these research efforts which explicitly described environmental issues for more than a decade.

need for joint action and the creation of a new world model. Lester R. Brown, head of the Worldwatch Institute, first outlined the idea of sustainability, which eventually led to the elaboration of the principle of sustainable development. This principle constituted the focal point of the UN World Commission on Environment and Development (WCED),[221] established in 1987, and chaired by the Prime Minister of Norway, Gro Harlem Bruntland. The essence of sustainable development is the following: sustainable development can be classified as development that meets the needs of the present without compromising the ability of future generations to meet theirs. The aim is to achieve harmony between man and the environment and also among humans.

For these aims and requirements to take effect, they must be more than just the foundation for national and international development action. *Needs* and *limitations* are the two core concepts of sustainable development. The principle of limitations does not define absolute values. Needs must be harmonized with available resources and the environment's capacity. Time must be provided for the regeneration of renewable resources. In the case of non-renewable resources, use must be adjusted to technological development, and the possibility of using alternative materials must be considered. The deposition of waste must be tailored to the environment's capacity to absorb it. The concept of sustainability involves meeting needs as a priority (primarily the basic needs of the poor). We must be aware, however, that the principle of balanced development requires a compromise which, being free from absolute restrictions, is acceptable to both over-consuming developed and over-populated developing societies.

Without international regulation even the most competent definition of tasks or action programs can fail. Realizing this, the expert group of the WCED brought forward a proposal relating to the legal principles of harmonious development which formed the basis of the first document promoted by the Bruntland Committee at the Rio Summit.

The Rio Summit, which highlighted increasing problems, became the biggest and most well recognized movement to proclaim social and political responsibility for the future of the Earth. From 178 UN member states 172 were represented, with 108 countries' heads of state or government in attendance. The summit was keenly anticipated. Not only was it expected to offer solutions to specific problems, but the hope was that it would resolve conflicts between

[221] Earlier, the UN had already set up committees to tackle certain strategic elements of global (but not environmental) problems. Such committees included the Brandt Committee (*Common Crisis: North-South Cooperation for World Recovery*) and the Palme Committee (*Common Security*).

developed and developing countries. Developing countries expected to be able to persuade developed ones to assign them 0.7% of their GDP, thereby enabling them to implement green technologies. Follow-up evaluations classified the event as both a success and a failure at the same time. It is a fact that certain documents and the issue of the financial means necessary to address basic problems sparked off fierce debates. Eventually, five documents were approved, although some of them were not real agreements.

a) The Rio Declaration on Environment and Development

The original plan was to have an Earth Charter document approved which would have included basic and firm commitments about environment protection and about support for developing countries. In the preparatory phase, this turned out to be unrealistic and a declaration was issued instead which included general principles but not specific decisions. The twenty-seven principles that were formulated have a lot in common with the ones approved in Stockholm in 1972. Such similarities include support for developing countries and their sovereignty, meaning acceptance of the fact that that they should utilize their resources following their own environmental and development strategies. *Promoting the necessity of sustainable development, emphasizing global interests, and states' common but differentiated responsibility were all new elements*. The 'polluter pays' principle was incorporated and states were instructed to provide accurate information in the case of transboundary pollution and to settle environment-related disputes amicably.

b) The United Nations Framework Convention on Climate Change (UNFCCC)

From the mid-1980s the need for the protection of the atmosphere became particularly significant along with the need to deal with the issue of global warming, a phenomenon caused by the greenhouse effect. The world awaited a convention from Rio which would guarantee a reduction of pollutant emissions into the atmosphere. Objections were raised against the restrictions on two sides. On the one hand, the USA, which was responsible for 17.6% of CO_2 emissions, did not accept explicit limit values due to its own economic interests. On the other hand, developing countries might have regarded restrictions as a kind of provocation, implying that they would have to give up their right to develop economically. Some of the developing countries also proclaimed that they would increase their emissions. As a result, the framework convention included basic compromises, and did not commit developing countries to make specific undertakings, or allot explicit reduction goals (percentages) for developed countries, even though it stressed their particular responsibility. It was the Kyoto Protocol which later extended the Convention in 1997 (see the following).

c) The Convention on Biological Diversity (CBD)

Scientists estimate that 5-30 million different species live on Earth, but if environmental damage continues at the present rate, by the middle of the twenty-first century 25% of all species may become extinct. The preservation of biological diversity and genetic reservoirs is a vital element of future biotechnological developments. The convention aims at preserving these resources and allocating the benefits arising from their utilization in a fair way.

It focuses on *traditional nature protection* and the *preservation and utilization of genetic resources*. It is a fundamental proposition that countries must not damage biological diversity through action outside their borders. Although each country sympathized with these objectives (they were particularly favourable to developing states, which were assumed to harbour larger genetic reserves), absolute success was undermined by the USA which refused to sign or ratify the convention.

d) The Forest Principles

The full name of the statement (*Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests*) makes it clear that conflicting interests prevented approval of the agreement by every party in spite of the fact that the majority acknowledged the alarming reduction of forest stands and the urgent need for forest protection. The prospect of a global agreement was jeopardized by countries whose economies relied significantly on timber exports. These countries rightfully claimed that countries which had already destroyed their forests hundreds of years earlier should actively financially support deforestation measures.

e) Agenda-21

This document is an agenda for action that is divided into four sections (*Social and Economic Dimensions*, *Conservation and Management of Resources for Development*, *Strengthening the Role of Major Groups*, and *Means of Implementation*), forty chapters, and one hundred programme areas. The last part deals with the financial resources and mechanisms needed for development, like granting aid to developing countries in accordance with GDP. It was agreed that the World Bank would transmit a certain portion of international aid to the *Global Environment Facility*, a new financing organization from which countries would be entitled to claim support for environmental development programs.

Apart from the above-mentioned documents, the conclusion of a convention (ultimately approved in 1994) dealing with desertification entitled *The United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (UNCCD)* was initiated at the Rio Summit.

16.1.3. The World Summit in Johannesburg in 2002 (UN World Summit on Sustainable Development)

The Rio Summit was a great environmental policy success with measurable results in terms of the specific agreements of forthcoming years. However, its successes seemed only temporary, thus another summit on environmental protection was needed. Some two hundred states (with eighty-two heads of state or government) were represented at the event in Johannesburg. However, looking under the surface we can see that the results of this event were only illusory. The Rio Summit can be pardoned for its lack of specific decisions as discussions were structured around an unfamiliar issue. Nonetheless, based on the processes started in Rio, the outcomes of Johannesburg can be regarded as a step backwards. Although the supporting material for the conference outlined real problems, the tune and reticence encountered at the event sent a message about attitudes to future environmental policy. Also, the summit encountered strong anti-globalisation and anti-American sentiments.

In the end, with numerous compromises, two documents were approved at the summit:

- The Johannesburg Declaration on Sustainable Development (containing thirty-seven points),
- A Plan of Implementation (one hundred and fifty-three points).

The issue of safe drinking water and certain social dimensions appeared as new challenges. In relation to these it was decided to halve the number of people who do not have access to safe drinking water and whose daily income is below $1 by 2015. Greater emphasis was placed on environmental health. The social dimension of sustainable development was also flagged up, thus environmental policy and social policy were linked.

Bearing the summit outcomes in mind, it is no surprise that some evaluations labeled the results unnecessary or insufficient. However, it is most noticeable that while parties were negotiating about global problems, in many cases state interests won out. Such events included the USA’s withdrawal from the Kyoto Protocol with regard to its greenhouse gas emissions (see Chapter 16.2.2). Another anticipated topic was support for developing countries, which seemed fair enough, but the developed states were of the view that poor countries should be expected to actually do something to protect the environment themselves, too. But the data revealed that struggling African countries were often spending more on armaments than on health care. Local despots often trafficked the aid sent to these countries. Even the wages of the UN Blue Helmets regularly dwindled in the distributing officers’ hands. In most African countries, democracy is non-existent. It has been replaced by thriving corruption and local terror tactics. Developed countries rule the global market, and by utilizing state agricultural aid systems they stymie the producers of underdeveloped ones. The fact was also suppressed that, in the host country – a high-risk area for AIDS – the president himself (among other factors) raised barriers to curing the disease, believing that the cause of the syndrome was malnutrition, not a virus. Clearly, due to persisting evasive attitudes the results of the World Summit in Johannesburg proved to be anything but an example of global thinking.

16.1.4. Rio de Janeiro 2012 (UN Conference on Sustainable Development – Future We Want)

As the environmental problems of our planet were becoming more and more specific, the intention to deal with them was manifested mainly in words. When the 2012 Rio Summit was at the preparatory phase, conflicting views were so serious that its success was put in doubt. Even though the large gathering was well-attended (fifty thousand participants, of whom three thousand were official delegates), the heads of several superpowers actively distanced themselves from the event, predestining it as a failure.

Some of the original goals of the conference included the greening of economies (in order to fight climate change), improving food safety, and tackling the environmental challenges of natural waters and oceans (primarily pollution, overfishing and biodiversity). To avoid an obvious failure, the 1992 Rio undertakings were not incorporated into the programme.

The decade-long conflict between developing and developed countries put a massive strain on the conference. The final resolution,[222] which is full of compromises, is more of wish list than an explicit and accountable schedule. Therefore, it might be considered reasonable that a number of negative reviews described it as disastrous. Someone even defined the following formula: Rio + 20 = 20 years in reverse. Nonetheless, the document of 283 points represents a comprehensive statement about our planet's environmental problems, elaborated with information about natural, economic and social factors. The document declared the need for the definition and approval of so-called sustainable development objectives. As a new element, it defined the requirement for access to an electricity supply of the whole population of the world by 2030. Moreover, a call was made for the proportion of renewable energy resources (at the time, 15%) to be doubled by 2030.

A peculiar idea was suggested; namely, to define a price for natural resources such as water, air, forests, etc. and marketization them, similarly to the current carbon-credit trading system. Yet, it is obvious that just as credit

[222] http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/66/288&Lang=E

trading has failed to fix the problem of carbon dioxide emissions, this general marketization would redistribute resources from the poor to the rich.

Although no progress was made with environment-related matters, several countries made substantive commitments. The Republic of Maldives announced the establishment of the world's largest marine conservation area, the republic of Mozambique drafted plans to green its economy, Great Britain undertook to oblige its large companies to measure their carbon footprints, and several leading banks lent their support to the development of public transport. These intentions demonstrate that if global cooperation fails, environmentally responsible initiatives must start one level lower.

Accepting the recommendations of the Rio Conference, in 2015 the UN renewed its previous development goals *(Millennium Development Goals – 2000)* and produced the *Sustainable Development Goals*[223] document, which places greater emphasis on environmental protection objectives. Among the 17 goals special roles are given to Goal Number 6: Clean water and sanitation, 7: Affordable and Clean Energy, 13: Climate Action, Protecting Biodiversity, 14: Life Below Water and 15: Life on Land.

The four global conferences that dealt with environment matters affirm that no substantive measures are taken until serious trouble arises. It seems today that the problems are clearly visible, but national interests are coming before global ones. However, countries' involvement in numerous issues is remarkably diverse. The best example of this may be with rising sea levels, which poses a direct threat to the very existence of some island states. For a long time only the European Union has tried to be the engine of change. Within the Union, global thinking has been an integral part of the economy for more than forty years.

However, there are positive signs as well. At the individual sectoral summits, professional matters were dealt with more specifically which contributed to the signing of significant agreements, as in many cases scientific reasoning managed to outweigh political interests. In the following sub-chapter we outline the most important agreements from different sectors.

16.2. The most significant environmental summits and conventions according to sector

16.2.1. The ozone convention and its consequences

Although some researchers proposed the possibility of damage to the ozone as early as the 1970s (the subject was touched on at the Stockholm Conference and was mentioned by two world models), the scientific world was surprised by the professional analysis of 1985 showing the extent of ozone depletion

[223] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

(see Chapter 5.3.2). In hindsight, it is unbelievable how fast the possible consequences dawned on politics. In the same year, an international convention in Vienna was convened to deal with placing restrictions on ozone-depleting materials. Much as it was only a framework convention, it entailed the coordination of voluntary reductions, measurements, and research. The significance of the Vienna agreement lay not in its achievements, but in its very existence. This was the first complex convention which led to a preventative agreement about a global environment matter before mankind suffered from any adverse effects.[224] This was followed by the *Montreal Protocol* in 1987, which detailed explicit obligations. It defined restrictions on five freon compounds (not to exceed the level of 1986, then to reduce levels by 20% until 1993 and by 50% by 1998). Moreover, it imposed moderate restrictions on three halon compounds. The Montreal limit values were followed by new, tightened sanctions. In 1990 in London the range of restricted substances was extended to include methyl bromoform and carbon tetrachloride, and the deadlines for their phasing out were moved forward. At the end of 1992 in Copenhagen it was decided to phase out halon compounds by 1994 and other ozone-depleting substances (CFC, CTC, MCF) by 1996. Also, further materials were restricted (HCFC, HBFC and methyl-bromide). Until the Vienna amendment of 1995 and the Beijing amendment of 1999, developing countries could have been granted an exemption from their obligations to adhere to the above-listed treaties. The amendments, however, defined valid deadlines for these countries too, even if they were not close ones, and a $440 million fund was established to help them achieve the related goals.

The rapid measures following the recognition of the ozone depletion problem and the drastic reduction in emissions produced tangible results. Emissions of ozone-depleting substances leveled off, then dropped significantly (Fig. 5.36). For some years it seemed that fifteen years after the first measures the desired results had been achieved. In the first years of 2000 the size and duration of the ozone hole somewhat decreased in the southern hemisphere. The recovery was particularly strong in 2002. However, the results were only temporary. Probably this was partly owing to countries with rapidly developing economies which had previously been granted an exemption. Similarly, broken old refrigerators and air conditioners added to the list of sources of pollution. We hoped that pollution would decline sooner or later, but a recent study[225] shows that the amount of CFC-11 in the

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[224] In Oregon (USA) the distribution of CFC sprays was banned as early as 1975.

[225] https://www.nature.com/articles/s41586-018-0106-2, according to information of July, 2018 (https://www.bbc.com/news/science-environment-44738952) the possible responsibility of Chinese construction companies.

atmosphere has increased considerably, which might imply a violation of the ozone treaty. However, the 2016 amendment of the Montreal Protocol (*Kigali Amendment*) related to HFCs aimed not only at protecting the ozone layer but also mitigating the greenhouse effect.

The success of the ozone treaty demonstrates what people can achieve to protect the environment once they are willing to act. The question is how fast these efforts will pay dividends. Since ozone-depleting substances remain in the atmosphere for a very long time (for up to 50-100 years), emission-reducing effects manifest rather slowly, meaning that the amount of the former will reach the level of 1980 only around 2080 (Fig. 16.1). Considering this, Figure 16.2 really puts things in perspective. As we can see, ozone treaties led to very strict restrictions in a very short period of time, but the depleted ozone layer will endanger our lives for a long time. Figure 16.2.b shows a case of inverse proportionality. Although emissions have been falling since the early 1990s, the number of people suffering from skin cancer due to greater UV radiation will rise for at least fifty years. In conclusion, experts' admonitions against exposing yourself to the summer sun are definitely not an empty threat.

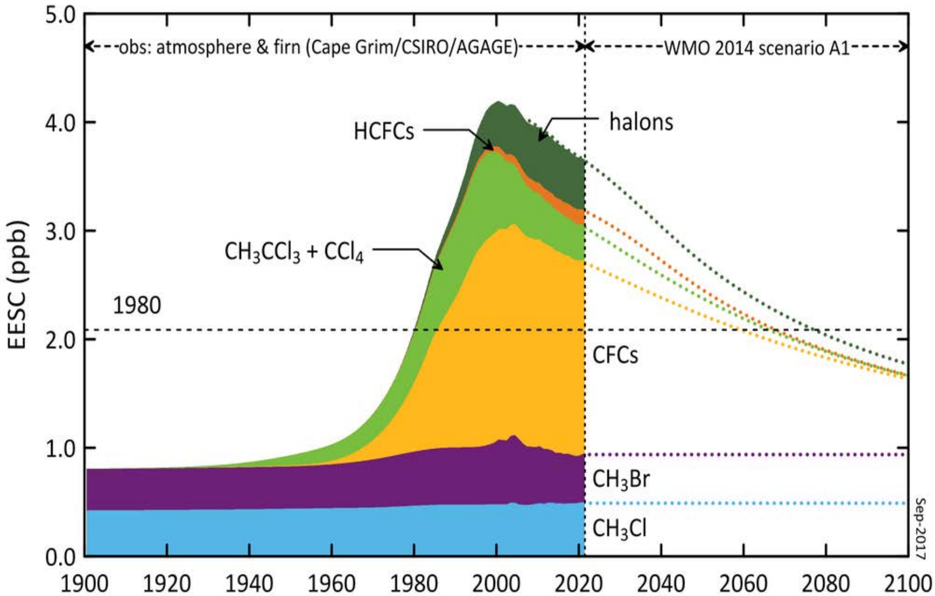

Fig. 16.1. Amount of ozone-depleting substances in the atmosphere between 1940 and 2010 and expected trends (Source: Klekociuk–Krummel 2017[226])

[226] https://theconversation.com/after-30-years-of-the-montreal-protocol-the-ozone-layer-is-gradually-healing-84051, EESC: equivalent effective stratospheric chlorine

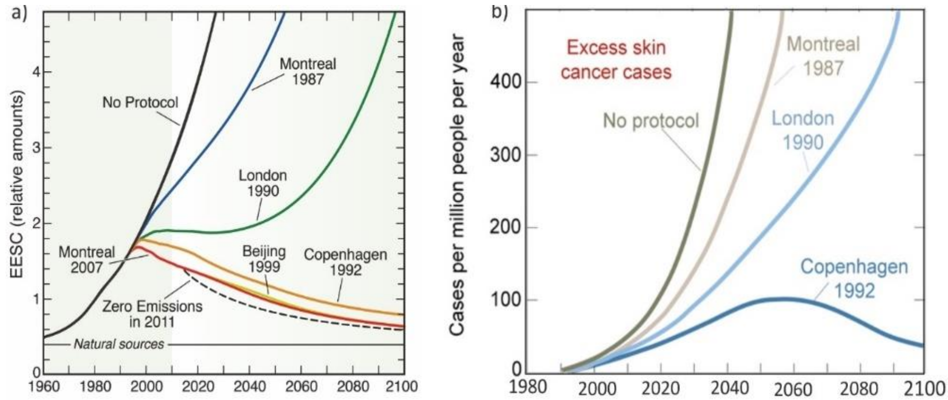

Fig. 16.2. Amount of ozone-depleting substances in the atmosphere on the basis of international conventions (a) and number of people predicted to suffer from skin cancer (b) (Source: UNEP)

As we have seen, measures for reducing the emissions of ozone-depleting substances have proved to be successful. Nonetheless, they highlight a specific problem: although the gases that substitute the harmful substances did not deplete the ozone layer, they turned out to be active greenhouse gases. So, in solving one problem, we exacerbated another. (Later this was addressed, too.)

16.2.2 Conventions on greenhouse gases

In the last third of the twentieth century, two important facts were revealed about the lower atmosphere. On the one hand, as a result of primarily human activities the amount of greenhouse gases had increased significantly, while on the other, the temperature had risen about 1 ^{o}C in the past one hundred years. These facts were hardly arguable, but the casual link between the two phenomena, due to numerous hardly quantifiable feedback processes, was difficult to prove. Anyhow, the countless warning signs introduced above triggered global thinking and action.

The first spectacular result was the *UN Climate Change Convention* approved at the Rio Summit in 1992. Previously, the public had been looking forward to a convention which would define explicit goals that would guarantee a reduction of the main culprit, carbon-dioxide. In the end, the approved convention became a special compromise between the European Community, which committed to keeping emissions at the 1990 level until 2000 and the USA, which firmly rejected this undertaking. This is the reason why the convention referred to the need to keep carbon-dioxide at previous levels instead of setting deadlines and limit values. Supplementary, separate protocols were later to include actual commitments, the same way as occurred with the ozone protocols. The compromise also meant that, taking further aspirations for development into account, it did not oblige developing countries to take on specific commitments, and did not define reductions in terms of percentages for developed states either. Former socialist countries were granted concessions regarding the scheduling of greenhouse gas reductions. The convention included the 'principle of common but differentiated responsibility' and the idea that developed countries should play a key role in responding to climate-change-related challenges. The convention urged that greater financial and technological support be provided to developing countries to minimize carbon-dioxide emissions. Despite the fact that the decisive majority of UN member states signed the convention, only thirty-seven developed and transition economy countries made commitments.

The convention has, however, launched a process. The Climate Change Conference in Berlin in 1995 was a milestone for change. The insurance sector voiced concerns about the role of global climate change in multiplying natural disasters. Island nations expressed their fear about a rise in sea levels. Moreover, the divide between developed countries became more emphasized – the majority did not adopt the standpoint of the USA.

The *Kyoto Protocol,* supplementing the UN Climate Change Framework Convention, brought about a revolutionary change. Thirty-eight countries and the European Union took on specific commitments and, initiated by the USA, they accepted special flexibility rules as well. Thanks to then-president Al Gore's environmentally responsible mindset, the attitude of the USA changed for the better. It was regarded as a general principle that the base date for measuring emission reductions should be 1990.[227] Emission restrictions applied to six gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6),[228] which are calculated together in terms of CO_2 equivalent (global warming potential – GWP), while committed countries get emission rights, too. Flexible realization is ensured by five mechanisms, which makes the protocol one of the most constructive environment protection conventions. The mechanisms are the following:

- *Time flexibility:* requirements shall be met using the average of a five-year period and not within one appointed year.
- *Emission flexibility:* the proportions of emissions of the six gases might change, but the total emission *equivalent* targets should be met.
- *'Sinks':* Emission reductions can be achieved not only by actually reducing emissions but also by removing CO_2 from the air (e.g. through biomass sinks). This is most efficiently achieved by afforestation.

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[227] Transition economy countries (that is, the former socialist countries) could choose a more favourable baseline (e.g. the period between 1985 and 1987 for Hungary).
[228] For the last three, the baseline year could be 1995.

- *Joint implementation and emission trading:* this was made possible between two countries with explicit commitments. A country is allowed to make emission-reducing investments in another country, and have a certain proportion of this acknowledged as its own reduction. Emission rights between such countries could also be the subject of trading.[229]
- *Clean development mechanism:* Committed countries could make emission-reducing investments in non-committed (i.e. economically less developed) countries, and have them acknowledged as their own reductions. Thus, developed countries were encouraged to make environmentally friendly investments beyond their borders.

Despite the fact that the principles were fair and clear, numerous problems arose. Countries' commitments were rather 'soft.' As the date of the Kyoto Conference drew closer, commitments were visibly weakening. (Considering the facts described above, the reason is obvious.) Consequently, the 5.2% reduction commitment taken on for 2008–2012 had been reduced to 4.6% by 2000. The convention also left a few loopholes through exemptions. Ratification was again a different story. After the USA withdrew from the convention in spring 2001, saying it was unfair to impose obligations only on developed countries, its ratification was jeopardized. Indeed, ratification was conditional on approval by countries responsible for 55% of harmful gas emissions. Although the treaty was signed by more than one hundred countries, it was ratified only in 2005 after Japan and Russia, two of the major emitters, had been successfully persuaded to join.

In spite of the protocol, the amount of greenhouse gases that have been emitted (calculated in GWP) has grown by 41% in 25 years (Fig. 16.3).

Much as the Kyoto convention is logical and would serve the future of mankind, its realization shows how negligent many leaders are about the prospects of future generations. The activity of the Intergovernmental Panel on Climate Change (IPCC) provided further proof of the strong link between greenhouse gas emissions and global warming. Everyday facts, such as extreme weather conditions, arctic ice and melting glaciers have made the process concrete. Facts have demonstrated, however, that while previously doubtful governments now accept the apparent correlations, hardly any parties are willing to engage in measures to do anything about it. Compared to the base year accepted by the Kyoto Protocol, greenhouse gas emissions had increased by 40% by 2017. As Figure 5.18 shows, there has been a significant change in the rank order of the major emitters in the past fifteen years. In 2006 China overtook the USA, becoming the greatest polluter.

[229] In the case of shared reductions, results for 2008–2012 were for investments realized after 2000, while trading started from 2008.

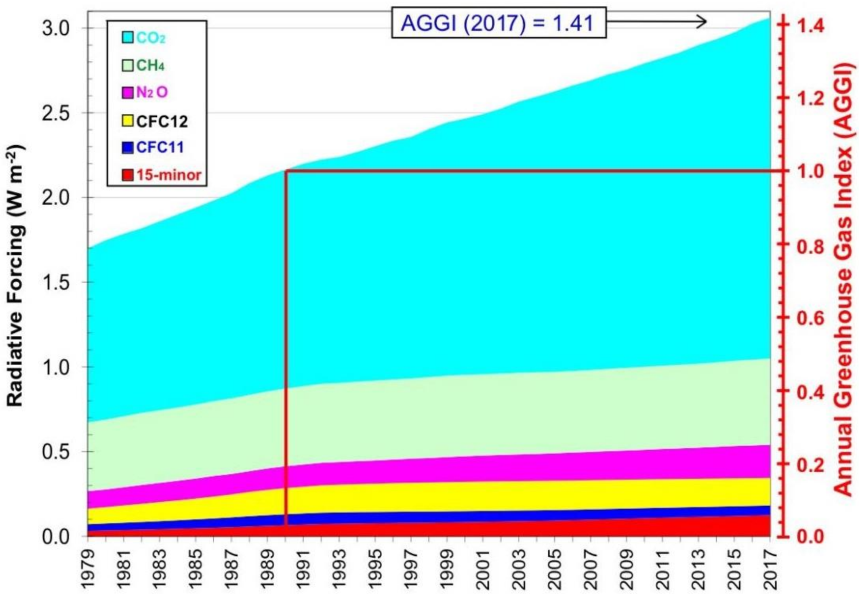

Fig. 16.3. Effect of greenhouse gas emissions and the Kyoto goal
(Source: NOAA 2018)

The Kyoto Protocol was designed to be effective until 2012, so since its ratification in 2005 the majority of countries have been seeking to create a new climate agreement. The greatest achievement of the annual negotiations has almost always been the same: to continue negotiations – without effective solutions. Simply put, nearly everyone agreed with the goals, but apart from the EU countries they were unwilling to take action. In a childish way, most countries point the finger at others, asserting that they are not the ones in charge. Of course, arguments can be backed up with some evidence from aptly used statistical data, but such partial truths will not reduce the amount of greenhouse gases. However, it is worth comparing countries' reasoning and the underlying facts. China, the biggest emitter, and India stated that their emissions per capita are only a fraction of the USA's, therefore they refuse to limit emissions. The EU and some developed countries wanted developing states with rapid economic growth to undertake that their economic development would not require emission growth of a similar magnitude; that is, they did not aim at reduction but the consideration of environmental criteria. Canada, while aware of the fact that its shale gas extraction prevented it from carrying out its former undertakings, would have preferred to have regulation that applied to the whole developing world. Saudi Arabia was against any kind of environmental pact which could endanger petroleum-based economic growth, but created a fund for the environmental friendly utilization of petroleum. The USA and some other significant emitters like Japan and Russia were averse to committing to exact figures. They only wanted a document which ordered developed countries to reduce their emissions by 20–40% by 2020. It should be noted that the USA did not put up uniform opposition to the spirit of the Kyoto Protocol either. In a book, Al Gore[230] lists using two pages the American cities which have already symbolically ratified the convention.

What can be done in a situation like this? Negotiate and persuade the bigger emitters, but even this is anything but a piece of cake. As CO_2 is not a gas emitted 'on-the-spot', the larger emitters will not immediately face the consequences of their own action. In vain is the EU willing to take measures. One swallow does not make a summer. The most significant dividend of annual negotiations was a commitment to continue based on the Kyoto Protocol of 2012, when developed countries promised to fulfil their undertakings by 2020.

The year 2015 was a turning point in this idleness about environmental policy. Towards the end of his second presidential term, Obama fought internal battles in the USA, China took effective action regarding the Kyoto goals (renewable energy, afforestation, etc.), and by the end of 2015 a miracle had occurred. The Paris Agreement was signed by 195 UNFCCC member states by June 2018, and 178 became party to it. It then seemed that consensus had been reached about perhaps one of the most crucial global environmental topics. The ultimate purpose of the Climate Change Conference in Paris was to keep global warming at no more than 2°C above the temperature it was before industrialization, and endeavour to keep warming below 1.5°C. Furthermore, countries stated their intention to reach net zero CO_2 emissions by the end of the century, thereby reducing climate-change related risks (Fig. 16.4).

According to the agreement, countries shall make nationally determined contributions to mitigate climate change by means of emission reductions, which shall be reported every five years, and every new contribution shall be more effective than the former ones. However, countries' contributions have no international legal force. To enter into force, the convention needed to be ratified by at least fifty-five countries which are responsible for at least 55% of greenhouse gas emissions. As a result of these loose conditions this situation was realized very quickly, in November 2016. Although the USA also ratified the agreement, following the change of president Trump has repeatedly proposed that the USA withdraw from the agreement, and by the time this book was published he had suspended his decision.

The Paris agreement can be regarded as a political success, but scholars and professional organizations do not have a high opinion of its professional content. According to the 2016 UNEP emission report, greenhouse gas emissions will

[230] Al Gore: An Inconvenient Truth - 2006.

reach 54–56 billion tons of carbon-dioxide equivalent by 2030, which is 12–14 billion tons more than the amount needed to keep a temperature rise below 2°C. If countries clearly meet their 'Parisian contributions' based on the emission levels forecast for 2030, the temperature will rise 2.9–3.4°C by the end of the century (compared to the pre-industrial period). In order to avoid severe climate change, the reduction should be at least 25% greater by 2030 than the contributions countries have pledged.

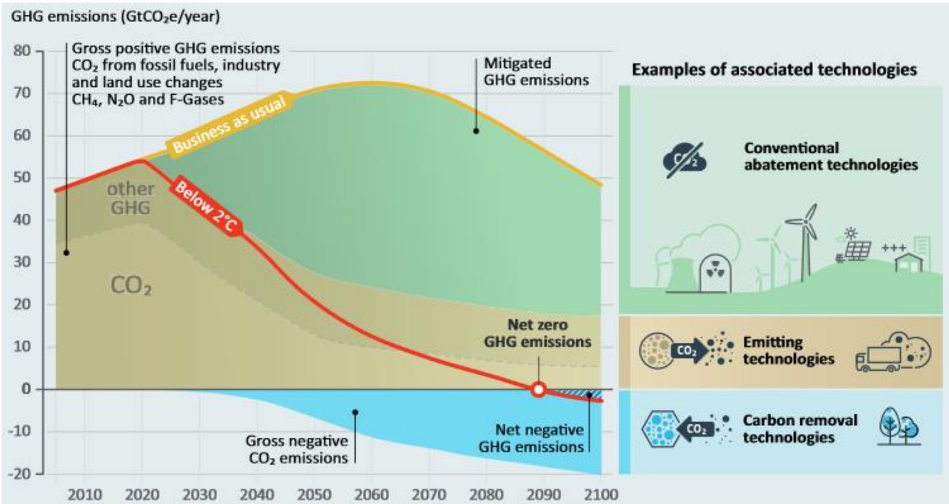

Fig. 16.4. The role of carbon dioxide removal in climate change mitigation, AKA a Parisian dream (Source: UNEP 2017)

The author of this book agrees with the critiques, and by adding some remarks would like to voice his concerns about the professional content of this agreement. In spite of the stricter legal consequences of the Kyoto Protocol, it failed to sufficiently mitigate greenhouse gas emissions (Fig. 16.3). When keeping to a 2°C rise is impossible, the 1.5°C Parisian goal seems frivolous, as a temperature rise of at least 1°C has already been locked in, and former studies reveal that the excess heat accumulated in the world's oceans will lead to a minimum of ½–1 °C temperature rise, even without a further increase in greenhouse gas emissions. Due to countries' inflexible commitments, achieving the goal of CO_2 mitigation seems unrealistic (Fig. 16.4). Taking a look at the habits and trends in global energy use, we can easily establish the fact that switching from carbon energy sources to non-carbon technologies within 1-2 decades is impossible without considerable restraint and the associated conflict (Fig. 16.5). In the context of increasing use, the three columns on the left should be substituted by the three columns on the right.

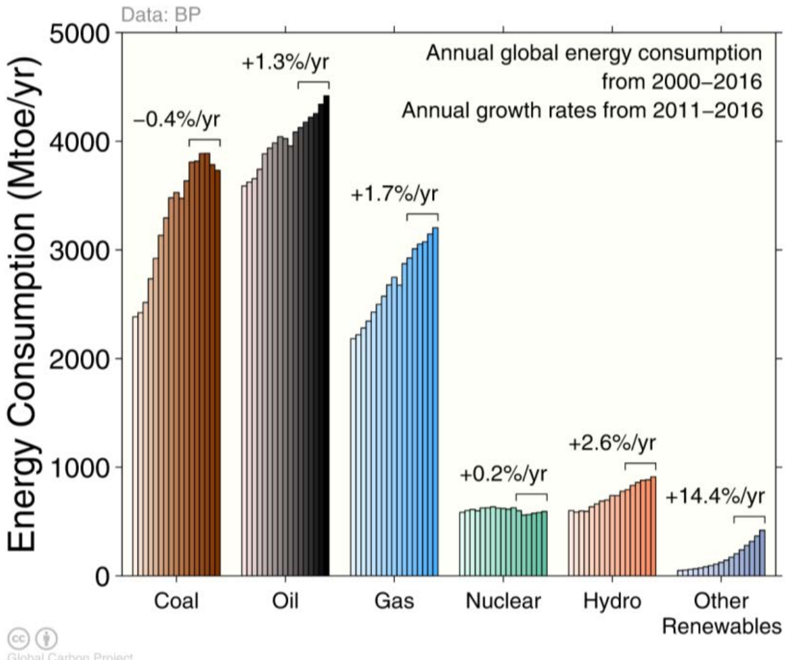

Fig. 16.5. Global energy consumption by energy type (2000–2016) (GCP 2017, Source: BP)

In 1997, when – with regard to the Kyoto Protocol – it had become obvious that politics was mobilizing little energy to mitigate global climate change, Donella Meadows, co-author of *The Limits to Growth,* published a fantastic essay in *The Global Citizen.*[231] Although politics has made many more promises since then, we have wasted plenty of time and real action is yet to be taken. Therefore, Meadow's words are of more relevance now than they were twenty years ago.

16.2.3. Agreements related to the effects of acid rain

While the majority of the ozone-depleting and greenhouse gases emitted into the atmosphere have global effects, the other group of air pollutants generally travel shorter, yet still considerable distances (thousands of kilometers), so emitters are more likely to face the impacts of pollution. Consequently, if a country wishes to ameliorate such problems by adopting environmentally responsible measures, it will have to deal with fewer international negotiations.

After it became clear that some transboundary pollution also has negative effects outside the country of emission, the UN Economic Commission created a comprehensive convention. The Convention on Long-range Transboundary Air

[231] http://donellameadows.org/archives/mother-gaia-reflects-on-the-global-climate-conference/ - This is a must-read.

Pollution (LRTAP)[232] was signed in Geneva in 1979. The document set out the targets of reducing the major pollutants associated with acid rain and acid deposition (first, only sulphur and nitrogen compounds), regular reporting, and the measurement and monitoring of pollutants. The convention was supplemented, or in fact 'concretized' by eight protocols by 2018 in relation to reducing regulated pollutant emissions, and extending their range. In connection with the convention a program for the financing of the *European Monitoring and Evaluation Programme* (EMEP) was approved in 1984. Accordingly, the program was set up to collect data about sulphur, nitrogen and volatile organic compound emissions, to measure air and precipitation quality, and to model the spread of these in the atmosphere.

Protocols additional to the Geneva Conventions gave content to the original documents. The protocol approved in Helsinki in 1985 prescribed that countries reduce sulphur emissions by 30% by 1985 compared to their emission levels of 1980. Regulation was issued in Sofia in 1988 about nitrogen oxides, stipulating that by 1994 emission levels should not exceed the level of 1987. In 1991 in Geneva a decision was made about the regulation of emissions of volatile organic compounds (VOC). Such substances mainly originate from fuel and solvent evaporation (e.g. gas, acetone, benzole, xylene, formaldehyde, etc.). These compounds endanger health and contribute significantly to photochemical smog. The regulation made the following stipulation: countries shall reduce substance quantities by 30% by 1999 compared to a 1984-1990 base period, or shall achieve the level of reduction undertaken in the Ozone Convention, or shall keep their emissions at under the level they were in 1988.

The Oslo Protocol determined further structural refinements and scheduled restrictions on sulphur emissions in 1994. Continuous evaluation showed that the majority of countries took these undertakings seriously, and made reductions faster that required and to a greater degree. Having recognized that atmospheric aerosols might contain heavy metals, restrictions were required to cover these materials as well. The protocol signed in Aarhus, Denmark in 1988 principally specified the need for the reduction of lead, cadmium and mercury emissions. Countries shall not exceed their emission levels of 1990, or the base year level between 1985 and 1995. The protocol takes particular account of the need for the application of the best available technologies which can support the replacement of lead in fuel, cadmium in batteries and mercury in electric apparatus, mercury vapour lamps, dental materials, pesticides and paints.

[232] As the convention was signed 'only' by European countries, the USA, Canada and some former Soviet countries, it can hardly be regarded as a global convention.

Another protocol was signed at the same time, restricting persistent organic materials. Many of these are soluble in fat and bioaccumulative (they collect in organisms), and have been found to cause significant health problems in typically seafood-consuming countries such as Canada and the Nordic States. Among other things, the convention envisaged the destruction of DDT, HCHs and PCBs and stipulated restrictions on dangerous materials such as dioxins, furans, PAH and HCB compounds at the levels of 1990. In the case of dioxins, it was high time for this regulation to enter into force, since Europe, the area most affected by the convention, is the most polluted continent in the world.

A protocol signed in Gothenburg, Sweden, in 1999 focused on abating acidification, eutrophication, and ground-level ozone. The emission of four substance groups (sulphur, nitrogen oxides, VOCs, and ammonia) was maximized. By 2010, in Europe shared reductions had to be achieved compared to the levels of 1990 in the following proportions: sulphur 63%, NO_x 41%, VOCs 40%, and ammonia 17%. The protocol drew special attention to dangerous activities, such as plant burning, the production of electricity, dry cleaning and transportation. The protocol remarked that, as a result of these interventions, areas in Europe affected by acidification shrank from 930,000 km^2 (measured in 1990) to 15,000 km^2, areas affected by eutrophication decreased from 1.65 million km^2 to 1.08 million km^2, the proportion of flora exposed to increased ozone depletion dropped below the 44% measured in 1990, and it is estimated that mortality triggered by air pollution declined by 47.5 thousand individuals annually.

The increasing content of air pollution protocols shows that technological development and scientific knowledge make the mitigation of air pollution and its related effects possible without impeding economic growth. The consequences of restrictions are indicated by the improvements in air pollution-related data (Fig. 16.6).

The focus of the former conventions was Europe, but the effects caused by acid rain in North America in the 1980s required a special program. The Acid Rain program launched in the USA in 1990 aimed at reducing annual sulphur dioxide and nitric oxide by ten and two million tons by 2010 (respectively), thus taking emissions back to below the levels of 1980. Later, Canada joined the program, too. The most notable reduction in emissions was achieved in the previously most polluted areas (Fig. 16.7). On a regional scale, sulphur deposition has decreased by 88%, while nitrogen deposition has decreased by 26–71% in twenty-five years.

In the past two decades acid rains have afflicted primarily Asia instead of North America and Europe. As shown in Chapter 5.5, the world's most polluted cities are situated in those areas. Lately, the situation has not changed significantly, except for in China. Conditions are aggravated by the fact that there are no emission conventions in Asia, and national regulations are only in a nascent phase. Over the past ten years, however, a revolution has been taking place in Asia in the area of air pollutant emissions, which includes sulphur dioxide, the main contributor to acid rain. An analysis published at the end of 2017[233] established that from the two large coal-using countries, China has reduced its SO_2 emissions by 75%, while India has increased it by 50% since 2007. Maps based on satellite images reflect this change.

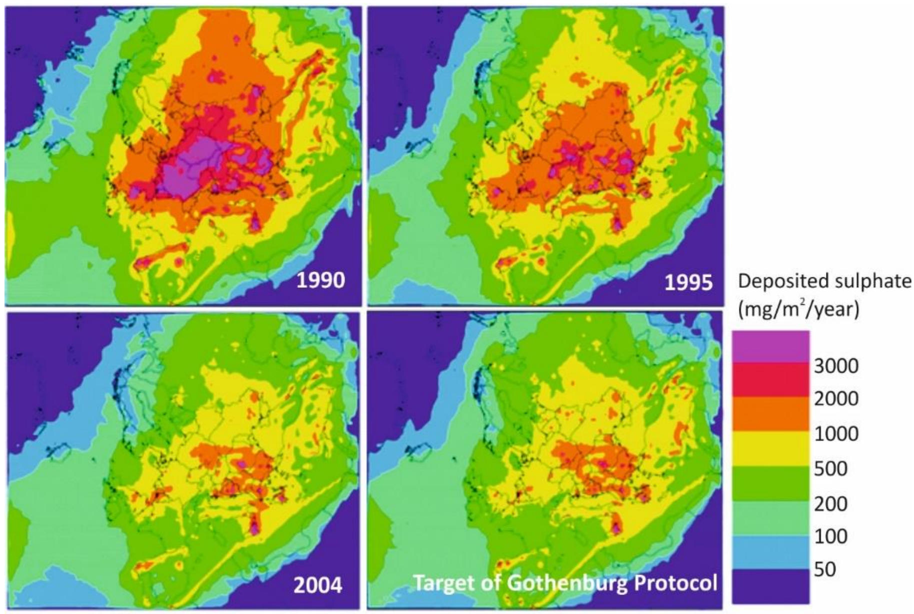

Fig. 16.6. Reductions in sulphate deposited in Europe as a result of emission reduction protocols (Source: EMEP 2006) (deposited sulphate, mg/m^2/year)

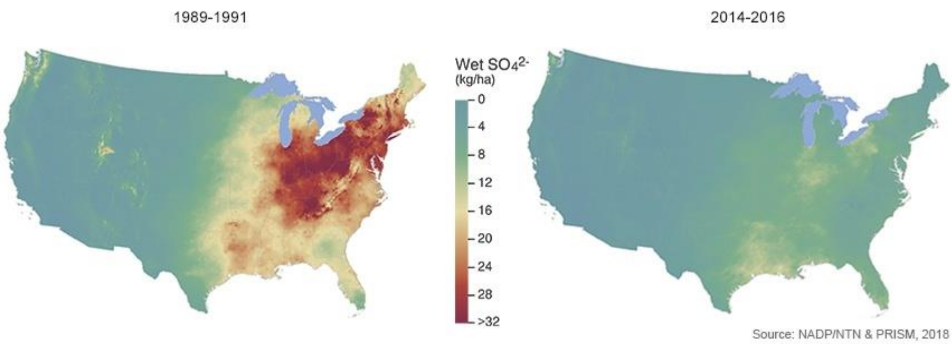

Fig. 16.7. Results of the Acid Rain program in terms of the depositions of sulphate (Source: EPA)

[233] https://www.nasa.gov/feature/goddard/2017/chinas-sulfur-dioxide-emissions-drop-indias-grow-over-last-decade

16.2.4 Major international agreements about the marine environment

For hundreds of centuries the world's oceans, except for coastal waters, were regarded as neutral territory which could be used freely by anybody. Arguments about the use of the sea flared up in the second half of the twentieth century when the deep waters around the continental shelves turned out to be a treasure trove of vast hydrocarbon deposits, and when the swelling fleets of faraway countries interfered with the fishing industries of coastal states. Another problem was that certain countries took advantage of 'unwanted' oceans by treating them as hazardous waste dumps. It was also revealed that anthropogenic pollution had had an enormous adverse impact on coastal waters.

The first comprehensive convention, the *London Dumping Convention,* ratified in 1972, dealt with the prevention of ocean waste deposits and prohibited waste from being dumped in the world's seas. Originally, it prohibited the deposition of radioactive materials and other highly dangerous matter into the oceans. Since 1994 it has prohibited incineration at seas and since 1995 it has forbidden the deposition of any industrial waste. Even if the objectives of the convention are clear, there have been numerous circumventions. For instance, Greenpeace made a documentary to prove that radioactive waste was being dumped years after the ratification of the document. This situation also played a part in the 're-issuing' of the subsequently supplemented convention in 1996.

The *London Dumping Convention* was supplemented by the MARPOL Convention (the International Convention for the Prevention of Pollution from Ships), produced in 1973 and renewed in 1978, which restricted the deposition of oil, waste, poison and poisonous liquids from vessels into the seas, and established standards for vessel structures and operation, and prohibited the deliberate dumping of pollutants carried by air into the seas. The benefits of the convention have manifested in a dramatic decrease in oil pollution in the seas (Fig. 16.8).

After a long period of preparation, the United Nations Convention on the Law of the Sea (UNCLOS) was concluded in 1982. The convention regulates nations' use of the seas. Technically, it terminated the above-mentioned 'unwanted' nature of the seas. It extended coastal nations' rights and determined 200-nautical-mile economic zones beside the traditional 12-nautical-mile national waters. This ruling applies both to waters and the use of the seabed. Therefore, although it didn't formally increase the size of countries' territories, the dividends from the extra utilization opportunities are almost equal to this. On this basis, the affected nations, but mainly Russia, are trying to obtain a favourable position concerning now ice-free Arctic waters. Apart from economics-focused agreements, the convention introduced measures for the protection, preservation and restoration of marine populations and against marine pollution.

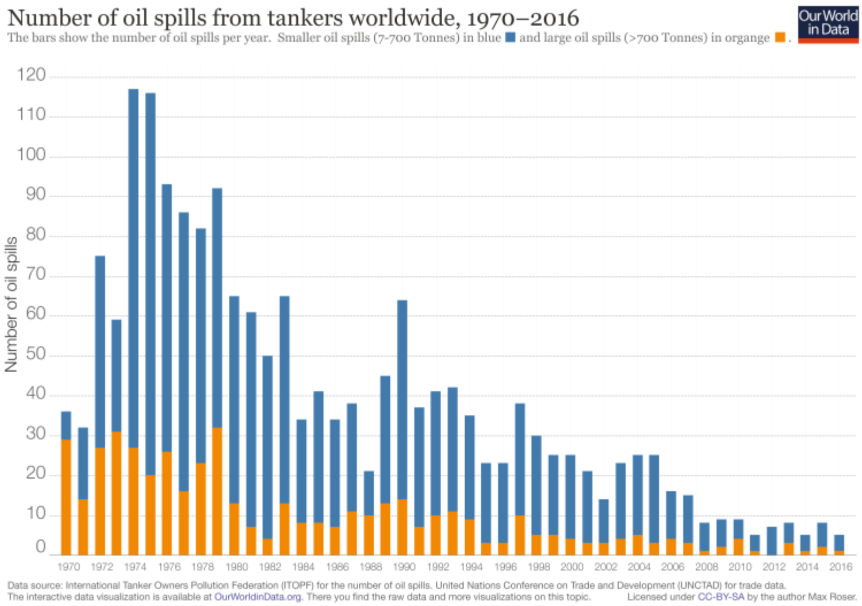

Fig. 16.8. Number of oil spills from tankers worldwide (1970–2016)
(Source: Our World in Data)

At first, regional agreements were concluded about the environmental challenges of coastal areas which highlighted the most affected regions (Arctic Sea 1974, Mediterranean Sea 1976, Kuwait region 1978, the broader Caribbean Sea 1983). Principles for the protection against pollution from land-based sources were formulated in 1985. In 1995 the Washington Declaration and a global program for action concerning the protection of the marine environment from land-based activities were signed.

Human activities do enormous harm to marine living resources. This impact is best demonstrated by the example of whales, the biggest creatures in the ocean, whose protection is of utmost importance. The International Convention for the Regulation of Whaling was signed in 1946. Its original aim was economic rationalization, but things changed when nations not or only scarcely affected by whaling enforced a ban on this activity in 1982. Since then, the convention has been highly disputed as countries with significant economic interests in whaling, such as Japan, Russia and Norway, would like to remove the ban, and regularly work around it. International conventions have taken some of the environmental pressure off the oceans. Still, plenty of examples prove that there are many anomalies concerning adherence to the relevant conventions. For instance, fishing vessels consistently abuse their rights to underdeveloped countries' fishing waters. They report a smaller catch, or simply violate the established quota for group waters, thus adding to overfishing.

16.2.5 International conventions on fresh water

There is no doubt that freshwater-related problems are of a global scale, although they are comprised of numerous local and regional components, and finding solutions to certain challenges would require specific local intervention instead of comprehensive settlements.

Chapter 6.1.8 (that deals with water challenges) showed that strongly opposing interests make it difficult to create comprehensive agreements, and it is inevitable that compromises must be worked out. Water-related global matters are fundamentally different to the problems of the atmosphere. When talking about the atmosphere, we can say that everybody shares the same problems. As far as the mitigation of transboundary pollution is concerned, polluters and those who sufferer share common interests, since some part of the pollution does harm locally. But when it comes to the problem of fresh water access, we can state that an ever smaller cake is required to feed an ever increasing number of people. Beyond a certain point, these demands are difficult to tolerate, and violent solutions may displace rational attempts at resolution. All this might make the content of water-related international conventions easier to understand, and explain the fact that the few comprehensive agreements include very few concrete elements. Issues concerning two or three countries cannot be solved generally; necessary compromises should be made locally.

In 1977 the UN organized the first water-themed conference in Mar del Plata, Argentina. Based on the approved action plan and increasing water-related problems, the 1980s was declared to be the decade of drinking water and wastewater drainage, but apart from raising awareness the conference did not deliver any tangible results. What is more, problems escalated.

After this, when preparing for the Rio Summit at the beginning of 1992, a separate water-themed conference was organized whereby the Dublin Statement on Water and Sustainable Development with its four major principles was formulated. Two of them are of utmost importance: 'Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment,' and 'Water has an economic value in all its competing uses and should be recognized as an economic good.' The time of unlimited water accessibility has passed: today it is regarded as a vital resource. As we could see at the beginning of this chapter, water was not among the separate topics at the Rio Summit, although Agenda 21 mentioned it several times.

The first global agreement was the Helsinki Water Convention (*Convention on the Protection and Use of Transboundary Watercourses and International Lakes*) which was approved in 1992. Although this was organized by the UN, it almost entirely applies to Europe.[234] The agreement underlines the fact that cooperation concerning the protection and use of transboundary watercourses is the responsibility of the affected countries, especially in the case of bi-or multilateral conventions based on equality and mutuality, and that countries should develop harmonized policies, programs and strategies about affected catchment areas. A notable further step would have been the UN Watercourse Convention concluded in New York in 1997 (*Convention on the Law of the Non-navigational Uses of International Watercourses*). But why the conditional 'would'? Because, although more than a hundred countries supported it, the convention only entered into force seventeen years later (in 2014), and as of 2018 only thirty-six countries had ratified it. The Convention focuses primarily on the quantitative issues of international watercourses, including water sharing, and creating collaborative solutions to related matters, but does not elaborate about water quality and ecology. The formulated commitments are rather recommendations. Although it suggests that compensation for damage is made at an international level, its basic deficiency is that its scope only extends to watercourses and then only certain sections of these, not including catchment areas.

The Dublin Conference proposed the establishment of an organization for coordinating water-related solutions. The *World Water Council* was founded in 1996. After that, the World Water Forum was organized every third year. The first event took place in Marrakesh, Morocco in 1997. The event referred to persisting tensions and forthcoming crises, and drew attention to the importance of raising awareness about sustainable water use. The second forum, held in the Hague in 2000, introduced specific problems according to area, and analyzed the future of water management that is predicted until 2025. No decisions were made at these forums, but the conclusions included major guidelines such as: water supplies shall not be monopolies, water-related services (purification, distribution and wastewater management) should not be free of charge (users must pay the real price of services), deprived persons should get compensation, and drinking water and wastewater drainage should be accessible to everybody based on their subjective rights. World Water Forums have been organized regularly since then, but owing to the distinctive features of the topic, challenges related to freshwater cannot be tackled globally. Solutions can only be produced at the regional level. The European Union has set a good example of this.

The *Water Framework Directive (WFD) entered into force in December 2000* in relation to the implementation of the common water policy shaped by the EU

[234] Apart from the European countries, only four Central Asian, former Soviet countries signed it.

in the mid-1990s. This document treats catchment areas as a natural unit, thereby promoting global thinking. Member States shall observe the stipulations of the Framework Directive. While new ideas were needed, the directive laid down new foundations for the entire field of water management. Its aim is to prevent further water quality deterioration, decrease the quantity of harmful substances that enter surface and groundwaters, promote the development of sustainable water use, reduce the effects of floods and droughts, and achieve the goals of international conventions. Its scope extends to surface- and groundwaters, aquatic ecosystems, and the protection of terrestrial ecosystems that directly depend on aquatic ecosystems, catchment management, the protection of water quality and quantity, reducing the emissions of harmful substances, and ensuring adequate water quality. The Framework Directive set out to guarantee good water quality until 2015 at the latest, which, in the case of surface waters applies to the ecological and chemical state of water bodies and in the case of groundwater applies to quantity and chemical status. Moreover, it instructs Member States and would-be Member States to prepare appropriate River Basin Management Plans (RBMP) according to the stipulations of the framework directive for their entire territory, which they should revise on a regular basis.

16.2.6 Conventions on nature protection

As already mentioned, a desire to protect nature triggered environmental thinking. The *International Union for the Conservation of Nature (*IUCN) initiated the 1961 establishment of the World Wildlife Fund (WWF), which in its initial stage focused primarily on protecting endangered species. In 1966, the first two volumes of the *Red Data Book* were published about the most vulnerable species. In the meantime, Carson published *Silent Spring* in 1962, which shone a light on the wildlife-threatening effect of chemicals. UNESCO, one of the UN's specialized agencies, launched the Man and Biosphere (MAB) programme in 1970.

In 1971 the Ramsar Convention (Iran) was concluded, which aimed at the conservation of rapidly decreasing wetlands. The convention does not include mandatory stipulations, as it allows for reasonable utilization. This is the reason why in many areas such land is often taken out of use. In May 2018, the total area under the convention in 169 countries[235] affecting 2,306 protected areas was 2.1 million km^2.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) was approved in Washington in 1973 with the aim of ensuring sufficient protection for endangered species.

[235] At the beginning of 2018, North Korea joined the convention.

The Bonn Convention (CMS) was signed in 1979. This framework agreement dealt with the conservation of migratory species of wild animals and was supplemented by additional protocols.

The most comprehensive nature protection convention was the Convention on Biological Diversity (CBD), approved at the Rio Summit in 1992. An additional document, the Cartagena Protocol (2000)*, aimed to ensure the safe handling, transport and use of living modified organisms.*

As seen above, consensus can be reached in the case of global environmental matters. It is commonly seen that the destruction of nature and species is easier to prove and more motivating than the majority of environment issues.

16.2.7 International conventions on waste disposal

The first international regulations for waste disposal were aimed at combating ocean pollution (London Convention, MARPOL Convention). Although the approved conventions reduced waste disposal at seas, countries kept circumventing them. In the 1980s waste disposal of industrial origin fell to a third, and oil pollution was reduced by 60%. The most spectacular infringements were tanker disasters, when vessels failed to comply with requirements. In December 2017, 193 countries signed a convention concerning the reduction of plastic waste disposed into the seas.

National legislation responded more slowly to anomalies in connection with waste disposal on land. This can be explained by the fact that problem areas are restricted to only a few countries instead of international territories. The Basel Convention (Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal) was signed in 1989. Its foundation was laid out in the principles for hazardous waste drawn up by the UNEP Governing Council in Cairo. First, the convention restricted, and then from 1994 prohibited industrialized countries' transportation, disposal and recycling of hazardous waste on the territory of developing countries. For a long time, recycling was the magic word that enabled circumvention of this regulation. The convention defined reporting and returning obligations, too. Just like any other convention, the worth of the Basel Convention can be measured by its effects. Of course, the situation has improved considerably in the past two decades, but in some regions infringement occurs on a daily basis. Some developing countries, and perhaps their corrupt officials who are interested in short-term dividends, accept 'pocket money' in exchange for letting hazardous waste in, and are negligent of its long-term consequences. This, again, is how global problems can cause local damage.

16.2.8 Acceptance of international conventions

In 2007, in a comprehensive evaluation (GEO4[236]), the UNEP surveyed fourteen international conventions which play a crucial role in the conservation of global values and the future of our planet. Some of them are yet to be mentioned here.

The most well-known of these may be the World Heritage Convention, which was approved in Paris in 1972. In a way it is quite unique, as countries have undertaken to protect and conserve the World Heritage sites situated on their own territories for later generations. Arguments usually arise only about the selection of sites which can enhance the PR of the relevant countries.

The number of registered chemicals exceeds ten million, from which over a hundred thousand are traded. Taking into account their potential hazards and their accumulation in organisms, they require special treatment. These issues are considered in the Rotterdam Convention (1998), which defined rules defined as *Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade*, and the Stockholm Convention (2001), which regulates highly hazardous, persistent organic pollutants (the so-called POPs).

The UNEP material does not mention the Aarhus Convention (*Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters*, 1988), although this plays a key role in ensuring sufficient social support for the environment. This convention states that members of society shall be provided with access to environment-related public information, and shall be guaranteed the opportunity to take part in decision-making. Persons who exercise their rights in compliance with the convention, cannot be punished. Countries shall raise awareness about access to information (e.g. making lists of information freely available), preferably also in electronic form, and ensure that environmental organizations get the deserved acknowledgement and support. Sadly, many countries fail to satisfy the requirements of the convention.

If we were to undertake a brief evaluation of the participation of the countries on Earth in the major environmental conventions, we would soon establish that they are generally theoretically accepted, while globally important issues are confirmed quickly at national levels, too. However, it is at the stage of the achievement of related, concrete tasks that progress often falters, despite the fact that the vast majority of UN member states are engaged in them (Fig. 16.9). The best example of this is the formerly introduced Kyoto Protocol, and the hassle that was encountered with the next climate convention, or the anomalies with waste disposal. Nevertheless, the international legal background of such global issues is more or less acceptable.

[236] http://web.unep.org/geo/assessments/global-assessments/global-environment-outlook-4

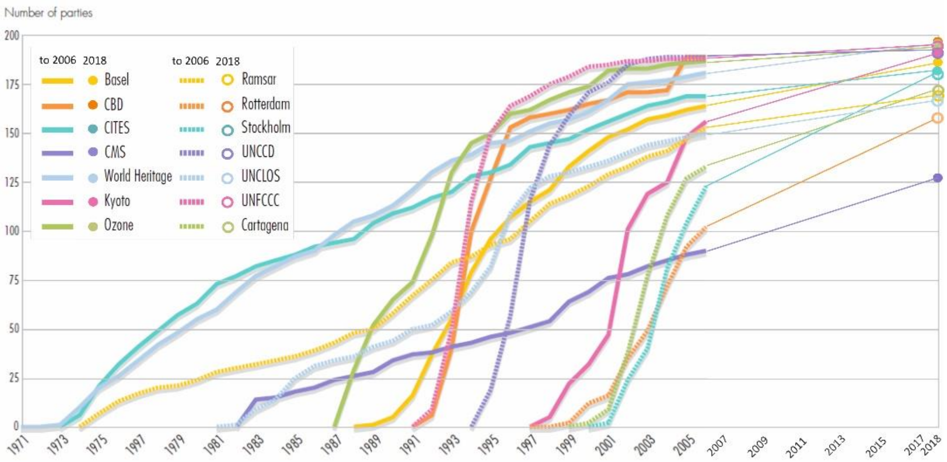

Fig. 16.9. Ratification of major multilateral environmental agreements (Source: UNEP 2007; supplemented)

16.3 Further opportunities for international environmental policy

We should underline two opportunities for international climate policy. First, it can allocate resources for researching and managing major environmental matters. In many cases, financial support or compensation from developed countries has contributed to the success of international agreements. However, experience has also proved that money is not enough, because poorer countries face numerous other, not necessarily environment-related problems. Moreover, developed countries often see that development resources are not allocated to the originally planned goals, but vanish in the depths of corrupt public administrations or in the treasuries of local despots.

The most important environmental fund is the Global Environment Facility, which was established prior to the Rio Summit (1992) to promote the goals of the latter, with a $300–400 million support mechanism in the early stages, which lately has risen to over $1 billion per year. The financial funding is supplied by thirty-nine so-called donor countries.[237] By 2017, the fund had provided $17.9 billion worth of support, which had mobilized a further $93.2 billion. As a result, more than 4,500 projects have been supported in 170 countries. Among these, areas include integrated water resources management, GHG emission reduction, the safe disposal of hazardous chemicals (e.g. ozone-depleting materials), sustainable forest management, and adaptation to climate change, etc.

[237] https://www.thegef.org/partners/countries-participants

Another significant area of support concerns research into global issues. The IPCC (Intergovernmental Panel on Climate Change) was established in 1988 to study climate change, which, considering its trigger factors and effects, is one of the most complex fields of study. Formally, it was founded by the UNEP (United Nations Environment Programme) and the WMO (World Meteorological Organization). However, as the name suggests, it is an Intergovernmental Panel which is supported by world governments. This is the reason why it got into a difficult position when contributions from its biggest supporter, the USA, were suspended by Trump. The organization does not carry out research, but summarizes the results of various pieces of research done by others, and disseminates highly elaborate research reports. The First Assessment Report was issued in 1990, while the sixth is to be published at the end of 2018.[238] Evaluations are not of a political nature, but can provide a basis for the climate-change related policies of governments. Since reports are based on the work of thousands of researchers, they represent the overall perspective of the relevant academic world. Although there have been times when attempts were made to undermine its prestige,[239] the international community has acknowledged its work and in 2006 the panel was awarded a Nobel Peace Prize (together with former USA vice president, Al Gore). Participation in the work of IPCC is welcome, and in the middle of 2018 the organization had 195 members.

16.4 The significance of countries' national environmental policy

As indicated above, when it comes to global issues truly sufficient environmental policy agreements regulated by international law can scarcely be formulated. It is faster and more effective for individual countries to make decisions on a national basis. Naturally, these may often go against individual interests in the short term (for example, in the case of banning smoking in public areas). A much more drastic intervention is enforced birth control in many countries.

In most cases, strategic national intervention is achieved only by allocating enormous financial resources or through the intense involvement of state administration. Good examples include the unique afforestation programme in China and its intervention against air pollution over the past decade, the acid rain programme of the USA, the saving of Lake Urmia in Iran, or the initiatives against plastic waste in the aforementioned countries. The citizens of developed countries are finally accustomed to collecting waste selectively, and the CO_2 emission quota system has contributed to companies' mitigation of greenhouse

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238 http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1
On the same webpage, further climate-change-related publications are available.
239 For detailed information, see the publication by Leggett.

gasses. Many countries have failed to make decisions in connection with air pollution, waste disposal, and hygiene-related issues, despite the fact that these can be tackled on a national level.

Sometimes the long-term success of centrally made decisions is questionable. Many water-supply-related interventions raise concerns. Such action has led to the environmental crises affecting Lake Chad, the Aral Sea, and many smaller bodies of water. The proportion of Saudi Arabia's agriculture that is being irrigated using non-renewable water resources is also seriously troubling.

How can citizens be galvanized into taking action about strategic global issues? – This is the question. To what extent will people become involved in the realization of local climate strategies when they are aware of the fact that their contributions are minimal on the global scale, while large greenhouse gas emitting countries are reluctant to cooperate?

17. Economic traps

17.1 Production constraints

Simplifying the reasons for global problems, we can state that a rapidly growing population and intensifying consumption are provoking a rapid increase in production, which is using up finite and barely renewable natural resources. Drivers of production may vary in different countries, but three core elements are constant.

a) Consumption pressure. On the one hand, the consumption needs of a growing population will increase, even if the demand of individuals do not increase, since more people have more needs. This problem hits developing countries hardest. On the other hand, due to the spread of consumerism, individual-level consumption is considerably increasing. The ingredients are the following: wasteful consumption, waste production, a wider range of products with disposable packaging, the spread of material- and energy-intensive products, and a culture of conspicuous consumption and a media that encourages consumption. These issues are typical of developed countries, and a strong correlation exists with GDP per capita. For instance, SUVs are becoming mainstream, as is air conditioning which in flats is often chosen over insulation, even if the latter would cut down heating costs and make summer cooling unnecessary. The best example of consumption pressure is the growth in the economy and consumption of China over the past two decades.

b) Development pressure. Economic development is the basis of political stability. The most commonly used indicator of development is not free time, environmental status, or well-being, but GDP. An increase in consumption is almost always a key element of political promises, which must be reinforced every 4-5 years. No matter how humane or globally minded, any programme that has the aim of stopping or moderating growth is doomed to fail. This is why the idea in the Meadows models of zero development was rejected.

c) Technological leaps. Each form of technology has significant resource needs. Switching to more developed variants is usually costly and wasteful, just like with the growing number of computers and other electric gadgets. Often, such items could be used for many more years, but our accelerating world urges us to change to more up-to-date technologies, otherwise we will fall behind. Computers, cameras and cell phones – these are the best indicators of change. Traditional cameras vanished many years ago, and even digital ones have been overshadowed by 'omniscient' smart phones. (Of course, in the meantime the social role of taking photos and making phone calls has been radically transformed.) The additional components of unused but still functional devices meet their destiny in landfills. Sure enough, multinational companies have a hand in this process. (Countless types of cell phones come out every year with different chargers or batteries but no real reason for this.)

17.2. Selling off our environment

For thousands of years man used Earth's resources for free, which typically meant finding food by hunting, fishing or harvesting. Until the industrial revolution use of the environment affected only the elements found on the surface of the planet, and with a few exceptions (deforestation and quarrying) did not cause substantial damage.

The proliferation of mining activities has taken the use of the environment to another level, and initiated the uncontrollable and wanton destruction of environmental goods. While in capitalism everything has a price, environmental use has not been included in the cost of goods and services. Neither the damage induced by raw material extraction (groundwater damage, soil subsidence, or waste heaps), nor production-created pollution (to air, water and waste) have been assigned a cost. Concession fees or state forms of tax have nothing to do with real environmental damage, but just provide a legal foundation for the extraction of goods. Therefore, we can state that over the past 150 years our environmental assets have been sold off.

Different levels of economic development and partly related environmental regulation have been to the detriment of our environment. The production of environment pollution and hazardous goods in poorer countries has led to serious environmental damage (the worst of which was the toxic industrial disaster in Bhopal). But we have already mentioned the issue of hazardous waste exports as well.

The greater part of the Earth's surface is covered by the world's oceans, which, apart from the economic zones, are neutral territory. Competition for the oceans' resources is fierce (overfishing, raw material extraction). Seas are taken advantage of, while no-one takes responsibility for their health. Who will collect all the waste that has accumulated? No market investor is likely to seize this opportunity. We can wait until the Sun degrades the enormous amount of plastic into microplastics, but the waste will not be eliminated but only become invisible – the pollution will remain in the water.

The first proclamation in the Stockholm Declaration on the Human Environment reads: 'Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment of a quality that permits a life of dignity and well-being …'. This principle was compromised when the company that provided the water supply in Cochabamba (Bolivia's fourth biggest city) was privatized. Not only did the price of water soar, but rainwater was also sold as part of this water.[240] After several months of conflict and the death of a student, citizens won the 'water war' against the government. This was one of the first examples of the selling off of common natural assets. Perhaps air will be next in the line. And what will be the decisive factor in the ownership and sale of finite, exhaustible resources?

17.3 The profit trap

The world today is moved by money. Individual-level consumption is intensifying in a world in which it is only what one has in one's wallet or on one's credit card that defines the limit to spending, and multinational companies are eager to generate larger and larger profits. There is a vast gap between the real production cost of many products and the cost to the consumer. The 'rollercoaster ride' of petroleum prices is a great example of profit maximization.

Public opinion recognizes that it is in the economic sphere that the most effective measures may be implemented to combat environmental crises. We should remember a key thought in an essay by Donella Meadows in which Mother Earth makes a remark about man. '*Money is one of their symbols. It's their way of keeping track, like poker chips or chess pieces, in a game they invented that has to do with which of them has power over whom. They can buy each other with their money chips, but they can't buy a sunny day or a clean river or an atmosphere that's back at 270 ppm* CO_2.'

240 https://web.archive.org/web/20070929151555/http://www.waterobservatory.org/library.cfm?refID=33711

No doubt, even the economy is facing environmental challenges, and efforts have been made to respond to them. However, in a capitalist economy, profit-seeking imposes restrictions on this endeavour. The soaring petroleum price in 2008 triggered significant developments in the field of renewable resources. Then, with rapidly declining oil prices it was also the economy which killed such initiatives, and made several 'new-age' companies bankrupt. It is also suggested that companies' environmental awareness is often part of PR programs for enhancing their market situation. In the case of the diesel scandal (in connection with car production), instead of reducing emissions manufacturers tried to improve their appearance. Much bigger conspiracies presumably exist in the pharmaceutical industry. Although new medicines may have spectacular results, the majority of the population are becoming drug addicts, which may not only weaken the efficiency of subsequent medicines, but also cause damage which is difficult to estimate in the long term.

The most effective pro-environment measures are not profit oriented. For example, the programs for afforestation, waste recovery and combating air pollution in China.

18. Where are we now?

To summarize the previous chapters, we can identify some partial successes – but they are scarcely enough to generate a sense of optimism.

a) Mankind with its effects on the environment has transformed the Earth. Our planet's population of humans together with its large domestic animals weighs ten times more than the sum of all wild large animals. In the last few centuries, through its activities mankind has become the key factor in biodiversity changes. Owing to our activities, thousands of species have become extinct, we have swept them out of their habitats, and have used and exploited them.

b) We have a planet of finite resources which is needed to satisfy the needs of a rapidly growing population. Although measures to moderate the rate of population growth have proved globally effective, improving living conditions will mean that the aforementioned statement remains valid for a long time. A good example of this is China, where despite the one-child family models population growth is due to continue for decades.

c) We are aware of a great number of environmental problems, but due to well-defined interests we try to underestimate them, or man's role in them. The best example of this is the relationship between CO_2 emissions and climate change. While there is general consensus about the matter, the president of the USA is presently questioning the facts that America's well-prepared research institutions and programs have been providing based on the most comprehensive data. In most cases, science and technological achievements have come up with solutions, but in our profit-oriented world these have only been achieved using state aid.

d) Several successful international conventions have been concluded in favour of the protection of our planet's environment, even if they often aimed at correcting only the consequences of human intervention. The ozone convention came about quickly, and led to a general consensus regarding the need to effectively reduce the production and emission of responsible countries. The more comprehensive the convention and the more it affects the economy, the less likely it is that states can reach a consensus. Although everybody is affected by climate change (to different degrees), the climate-change framework agreement shows that common interests do not guarantee success if local interests are stronger. On account of shale gas extraction, which became economically viable (and extremely hazardous to the environment) after the rise in price of petroleum, Canada withdrew from the Kyoto Protocol. The overfishing of certain species has led to prohibitions. It is a slight exaggeration perhaps, but having no other choice fisheries were compelled to accept them. In the case of regional conventions, the key to success depends on leveraging common interests. Conflicting interests hinder the identification of this common ground. The water use of transnational rivers is a great example of this.

e) Over the last two decades, scientific knowledge has made progress, whereas practical environmental policy, with its apparently enthusiastic but in fact rather passive attitude, has regressed. The comprehensive environmental summits are testament to this. The process that started in Rio in 1992 lost momentum at the two subsequent events due to a lack of sufficient decisions. Although the background material for these conferences was more detailed and well-founded, the number of participating state leaders showed the decrease in interest in dealing with the issues, especially in the case of economically advanced nations, which, in the absence of responsible decision-makers, led to the failure of compromises. The major result of both comprehensive conferences and the climate change conferences was that it was agreed to continue the programs; that is, the conflicts were not so intractable as to undermine this goal.

f) *We are running out of time, our brakes don't work, our reaction time is slow, and we are heading toward the precipice.* Even in the 1970s the Meadows models drew attention to the need for immediate action, and warned that delay may result in disaster. We now see for ourselves that in vain was the production of ozone-depleting materials reduced and then banned straight away, as twenty-five years later the size of the ozone hole still exceeds twenty million km^2 in the Antarctic every year (the only good news is that it is below thirty million km^2).

The majority of scholars find it obvious that the key goal as regards combating global warming is to reduce emissions of greenhouse gases, mainly CO_2. Instead of taking sufficient measures, politics has been supporting economy's stalling tactics for more than twenty years, as demonstrated by the poor results of the Kyoto Protocol. The efficiency of making voluntary, responsibility-free emission reductions is highly doubtful. As I see it, the culmination of this is the articulation of the goal of 1.5°C. Why did we try to deceive ourselves with illusory goals when it was evident that this was unlikely to prevent a 2°C temperature rise (compared to pre-industrial levels)? I can explain this using an analogy. A sportsman will be successful as a result of their everyday endeavors (training), not their ambition to set world records. I feel that this global 'pro-forma' action is making achieving even more realistic goals impossible. The truth is that not even a 2-3-4°C global temperature rise will jeopardize the existence of mankind. But our present way of life will allow the maintenance of fewer people on Earth.

g) We are overusing many of our environmental resources. Our raw materials are finite, and extracting them is becoming more and more costly. However, we are allocating vast financial resources to armaments. Following the tranquil decades of the post-Cold War period, a tri-polar power politics is slowly unfolding. We should not have illusions about the reasons for military force. If the occasion requires, power politics will strike. This reminds me of a popular children's game, so-called 'musical chairs'.

The game involves chairs, one fewer than the number of players, placed in a circle. Players continuously walk or dance around the chairs, and at a signal they sit down. The player who fails to take a seat is eliminated. Then a chair is removed, and the process is repeated until there is only one chair left. The player who takes the last seat wins the game.[241] Let's modify the conditions of this game a bit. Imagine having ten chairs more than there are players. This way, in the first eleven rounds (while there are enough chairs for everyone), no player is eliminated. This is what our planet looked like in past centuries. We had more resources than the population needed. Now, let's change one more thing. Chairs can be taken by players who can seize them. Thus a faster and more skilful five-year-old child still has no chance to beat a huge, robust security guard. This is the direction in which we are heading with our shrinking pool of resources, and this is how the above-mentioned power politics may gain momentum. On top of this, there are more nuclear armed countries than the main superpowers.

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[241] A game played by children and adults:
https://www.youtube.com/watch?v=wZ3LZTT-FIY and
https://www.youtube.com/watch?v=uMnb-6_psbQ

19. Should we pack or should we stay?

Towards the end of this book, we should address an important question. Shall we take Stephen Hawking's advice about starting to populate a new planet for mankind within a hundred years?

Humanity is drawing down Earth's resources at an alarming rate, and this does not bode well for our future. While some people lead a comfortable life without thinking about the cost their situation causes to others, tens of millions of environmental refugees are leaving their homes, hundreds of millions of people are starving (their main daily challenge is to get food), and billions are fighting for the right to a decent life. Whichever group of people we pick, there is hardly anyone who really cares about the environmental question. Most people have no idea about the crises of various types that are about to hit. However, sooner or later, virtually everyone will be affected.

Human knowledge might find solutions in numerous areas. The world food crisis which was deemed critical half a century ago was not only resolved, but has created many reserves as well. If we do not continue to throw away part of our food, and replace our lavish meat-based diets with plant-based ones, our planet will be able to feed more people.

Mankind might be able to utilize a much greater proportion of renewable energy, even though the issue of its storage (due to the erratic nature of production) is yet to be solved.

Developed countries have already proved that the growing amount of waste can be successfully recycled into raw materials if such schemes are socially supported.

Many of our raw material supplies are running short. Although in the past decades new supplies have been discovered, this tendency cannot last forever. Still, the world's oceans can provide us with a lot of raw material, and we don't know what new ores may yet be discovered.

Due to the erratic location of freshwater, water crises are likely to worsen in many regions of the Earth. We will need to radically change our water use. The first step in this process is desalination, but what will happen to those who lack even salt water? Although the topic is all over the news, many underestimate the consequences of ongoing climate change, try to disclaim human responsibility, and postpone the required action.

Based on the above trends, we may delude ourselves with optimism, but our situation is not promising at all. We must not forget the facts introduced in Chapter 3. In the early 1970s two out of the three Meadows models forecast a serious crisis occurring in the mid-twenty-first century. One model indicated a significant population decrease (and the rate of this did not suggest natural mortality), while the other suggested zero economic growth as a means of survival. A recent study issued in the middle of 2018 that applied an entirely different research logic (extending mathematical models to include exoplanets) came to the same conclusion as the Meadows model.[242] The title that referred to the content of the research needs no further explanation: '*Alien apocalypse: Can any civilization make it through climate change?*'[243]; 'END OF THE WORLD: 70 percent of humanity will DIE in shock DOOMSDAY scenario.'[244]

Thus should we seriously contemplate leaving our planet, as Hawking suggested? Numerous bits of sci-fi have already dealt with the conquest of outer space. However, we do not have to be fortune tellers to see that this alternative cannot be the solution for the whole human race. We do not have enough resources to send tens or hundreds of thousands of people into space. Even after arriving on a planet identical to Earth, we would face a series of insoluble problems, such as how to supply enough food. A fresh start would be easier, even on a severely polluted, exploited Earth than on an entirely unknown planet for a few dozen settlers. Man has taken control of wildlife, and has reached the point where, beside natural forces, humanity itself represents the biggest threat to its own future. We have seen that global environmental problems can be effectively tackled in tandem with socioeconomic processes. The extreme situations that occur in certain regions (wars, and terrorist attacks) detract enormous energy from environmental problem-solving. The examples provided in this book show not only our environmental responsibility, but also the power of human knowledge. The basic question concerning mankind's future is when and how this knowledge can be used to tackle global challenges. Another question is whether the moral responsibility of major powers concerning global matters will be greater than their desire for power.

The situation on Earth has several advantages over the situation on an unknown planet. It is true that our resources are limited, but we have diverse forms of knowledge and a sufficient number of people and means of taking action. What we need is more foresight, co-operation and efficient action. We should act now, before it is too late.

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242 We also note that, at the time of the preparation of the Meadows model, the impact of climate change was not fully recognized.

243 http://www.rochester.edu/newscenter/astrobiology-alien-apocalypse-can-any-civilization-make-it-through-climate-change-322232/

244 https://www.express.co.uk/news/science/968076/End-of-the-world-doomsday-science-news-climate-change-cataclysm

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Global and Geopolitical Environmental Challenges

This book provides an overview of the current state of play of our global environment, citing examples to illustrate common challenges from all around the world. It also summarizes the findings of preexisting global models about the future of development and the worldwide policies and activities that have thus far been proposed to handle environmental challenges and the challenge of Sustainable Development. This comprehensive study ends with conclusions about our highly uncertain next few decades. A geographical approach has been applied to describe global challenges and policies which synthesizes many different sectoral and thematic issues at the regional and global level.

János Rakonczai, the author of this book, is a geographer and professor (DSc) at the University of Szeged, guest lecturer at Corvinus University of Budapest. His main fields of research are the assessment of human influence on the environment and the evaluation of climate-change impacts on the landscapes of the Hungarian Great Plain. He is the author of numerous course materials; furthermore has has taught university courses about global environmental problems for more than 20 years.